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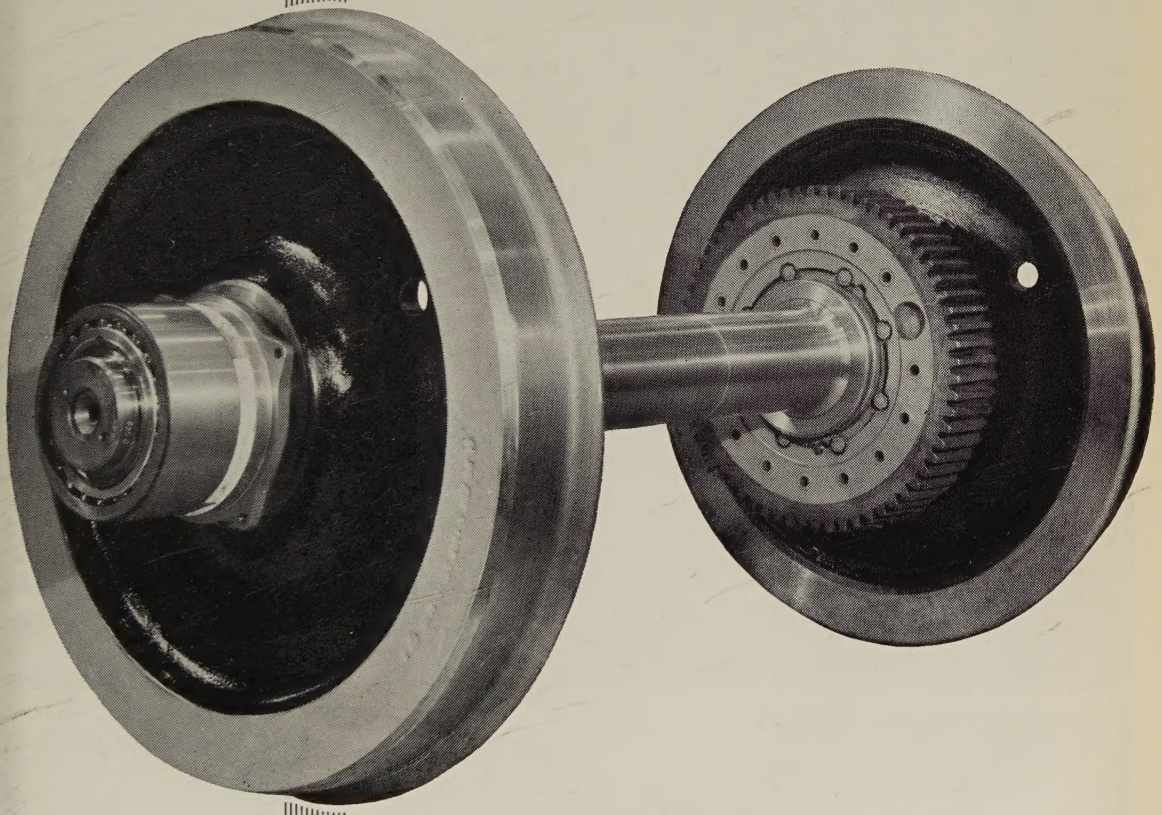

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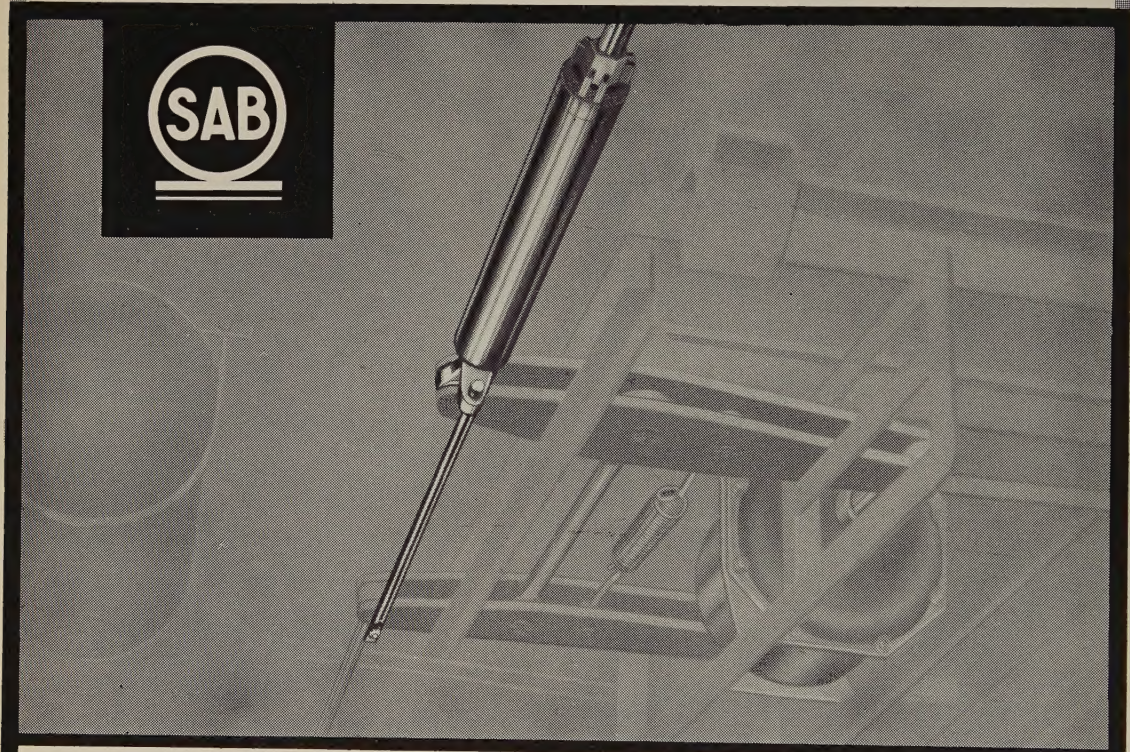

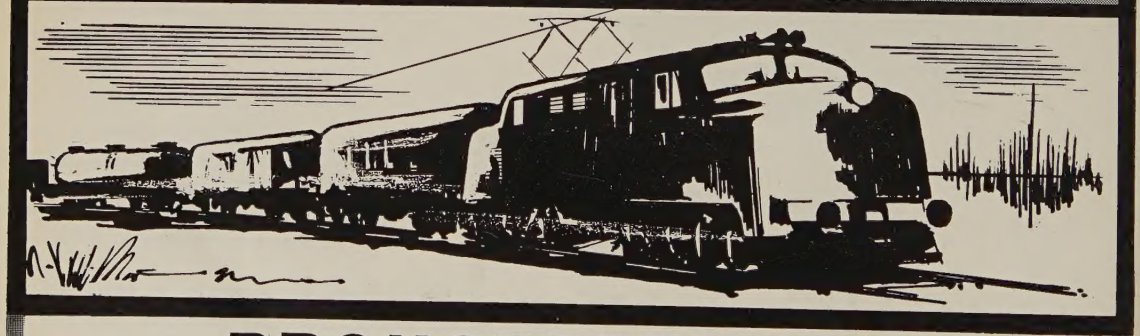

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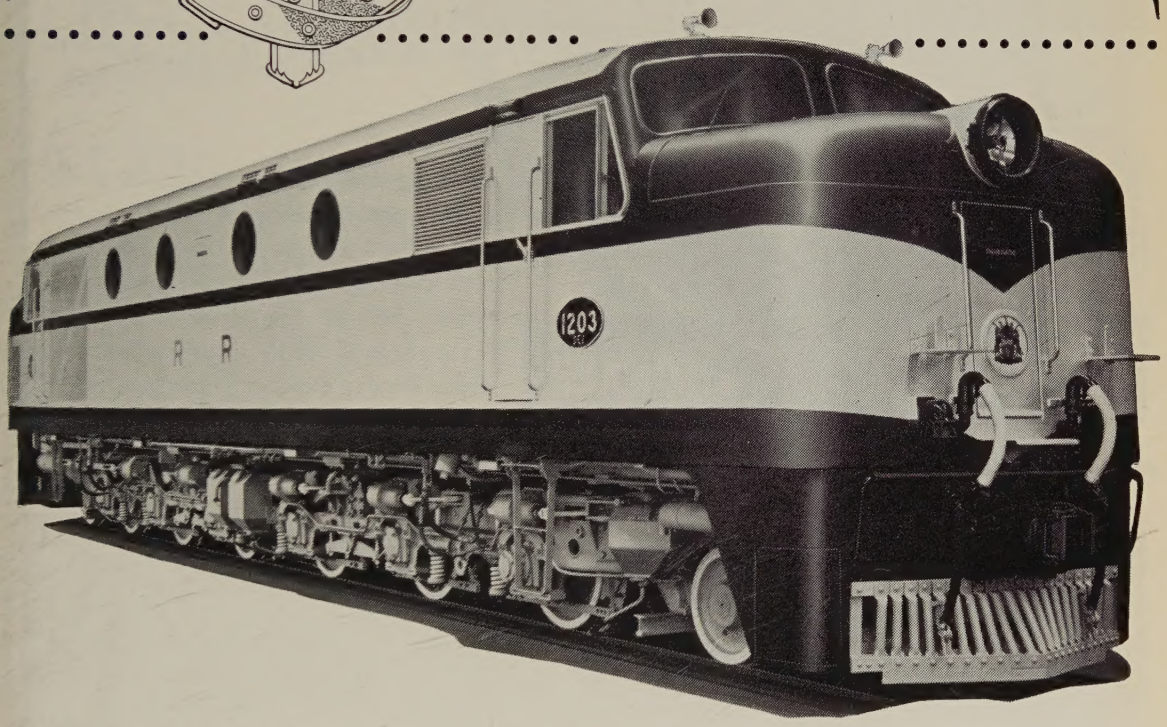

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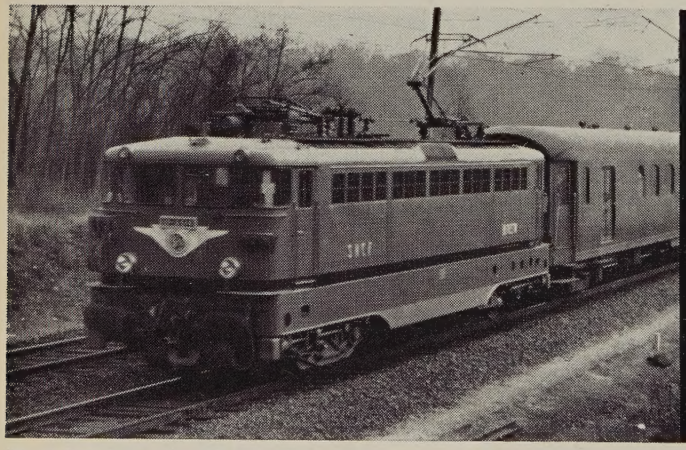

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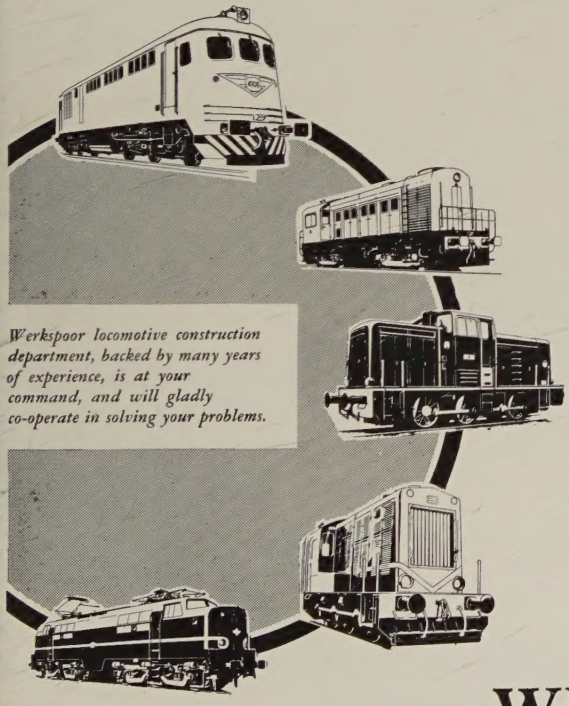

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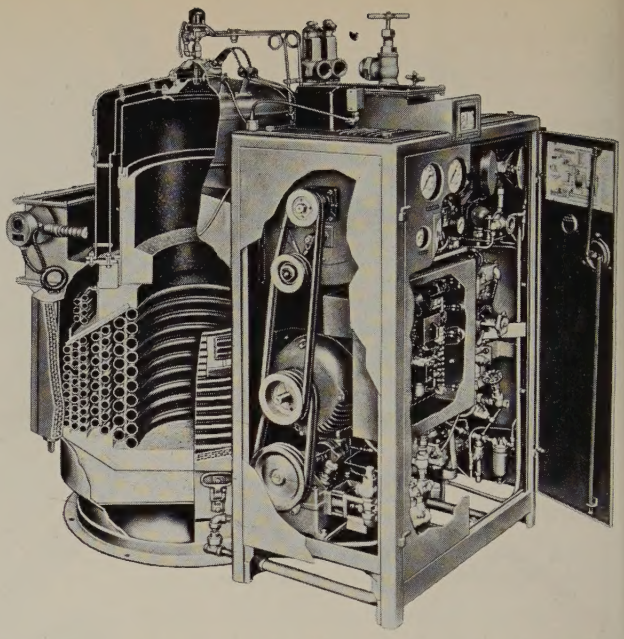

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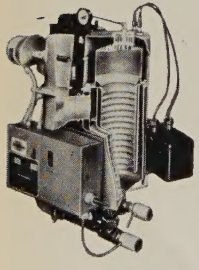

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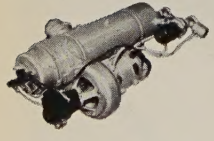

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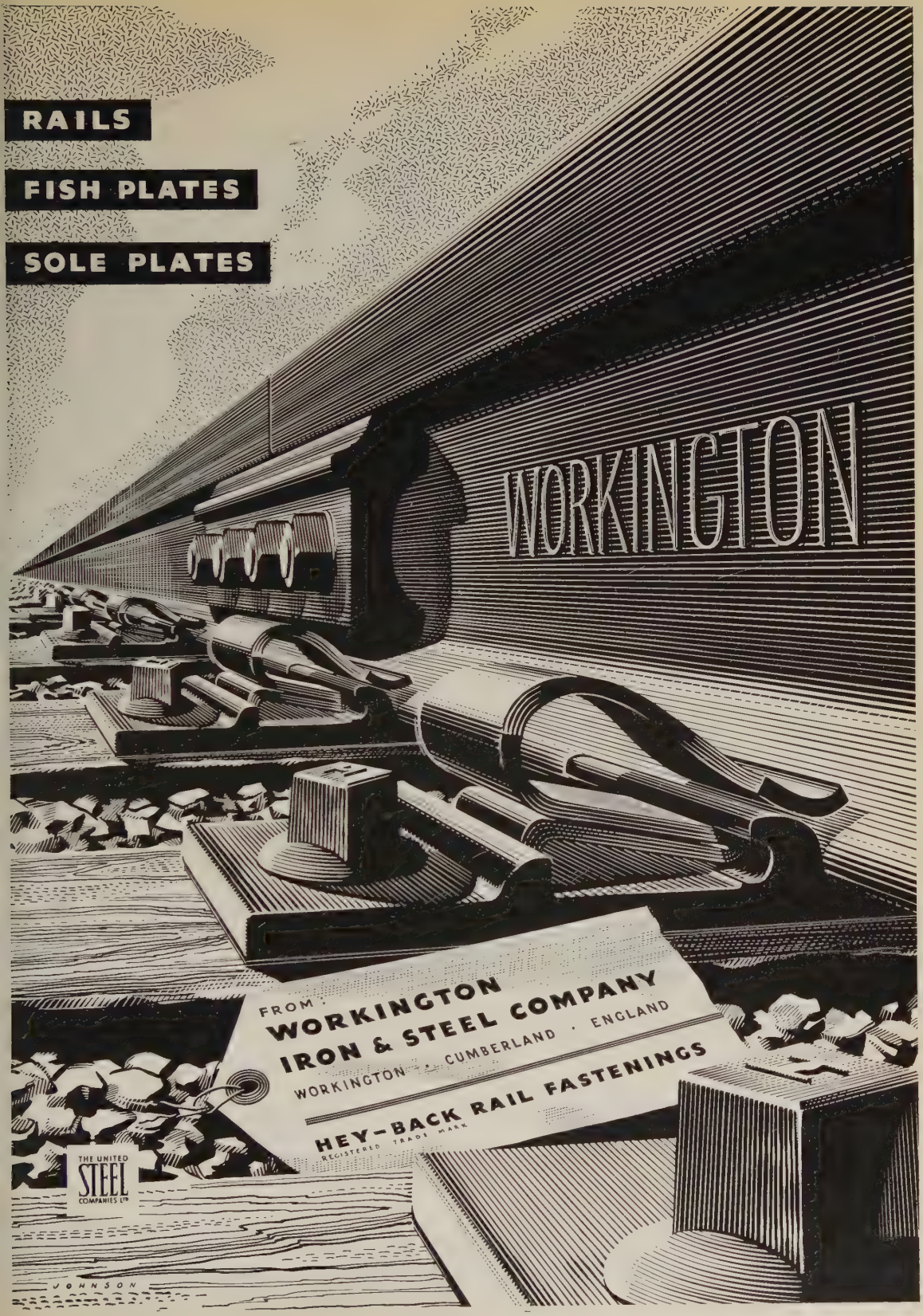
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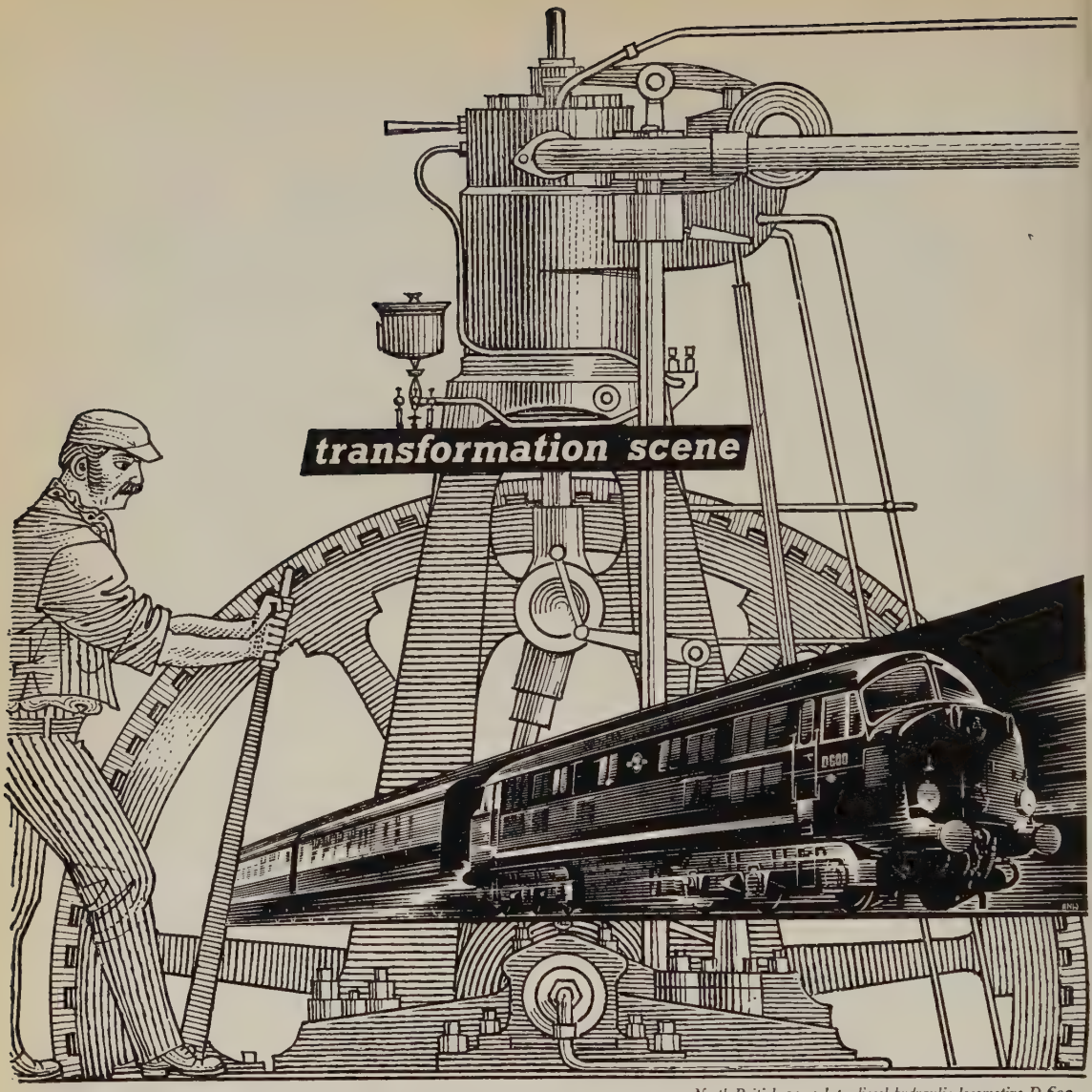

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BULLETIN
OF THE
INTERNATIONAL RAILWAY CONGRESS
ASSOCIATION
(ENGLISH EDITION)

[656 .25 (44)]

The progress achieved in applying automatic working to the signalling of the Dole-Vallorbe line,

by J. WALTER,

Ingénieur en Chef à la Société Nationale des Chemins de fer Français.
Chef de la Division des Installations de Sécurité, de Télécommunication et de Caténaires.

The purpose of the present article is to describe the leading features of the signalling equipment installed recently by the S.N.C.F. between Dole and Vallorbe, on the line from Paris to Lausanne, for the purpose of handling the increased traffic which will be required to pass over this important international route as a consequence of its electrification on the 25 000 V, 50 cycle system, taking power from the industrial network. This increased traffic is to be dealt with over fewer tracks, the line having been singled as shown in figure 1, with the aid more particularly of improved electronic equipment, which in turn will enable practically all intervention on the part of the station staffs in the running of the trains to be eliminated.

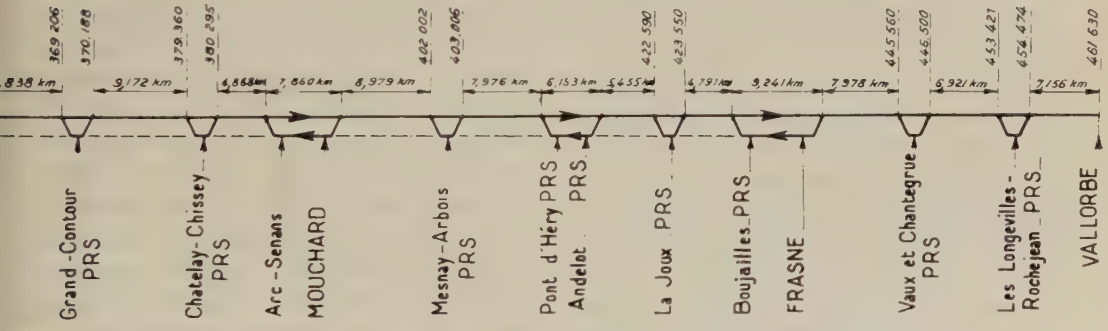

Fig. 1. — *Dole-Vallorbe.*
Diagram of the line showing portions originally double but converted to single line.

Such a plan possesses a number of advantages. In addition to reducing the work required at the stations, it enables considerable economies to be realised, firstly as regards the permanent way, of which a large amount, due for renewal, has been removed, and secondly, as regards the work of electrification, not merely because the amount of track to

be dealt with is much less but also because the need for one overhead contact wire instead of two in the tunnels greatly simplifies the work. Finally, as will appear in due course, the safety conditions provided for by the scheme combined with a high degree of automation in the working, form a very complete and well co-ordinated whole.

Much thought and investigation was required to perfect this plan, during which it became evident that there was everything to be gained by developing still further what may be called the classical arrangements such as the single line automatic block, electric power signalboxes at the stations, remote control devices, centralisation of controls and return indications, etc. A combined effort to this end was made therefore by the railway authorities concerned and the signalling firms, in an endeavour to arrive at the most fitting solution to this very large problem. These efforts found expression essentially in various advances made in two directions and affecting in the one case the signalling installations using electro-magnetic type relays (this first step having reference to apparatus and assemblies already often used but to which certain improvements have been made), and, in the other case, the introduction into such installations of electronic devices offering for the first time in this field very valuable facilities and enabling an excellence of working hitherto unknown to be attained.

The present description will deal first with the automatic block and the signalboxes in the stations; after this, details will be given concerning the centralised control with its facilities for the storage of route setting controls. (It happens that the first items involve electro-magnetic type equipment while the second refer to apparatus in which electronics have come to play a decisive part in railway signal engineering [1].)

PART ONE.

AUTOMATIC BLOCK AND ELECTRIC POWER SIGNALBOXES OF STATIONS.

1. Single line automatic block.

As the general tendency seen in all new installations is to increase the degree of automatic working as compared with the arrangements usually employed hitherto, it was fitting to begin by replacing the manually operated block by automatic signalling.

This involves some special features, referred to hereafter; the maximum length of the block sections is appreciably greater than that seen as yet in France with automatic signalling. In previous installations, a maximum of 2 km had been adhered to in practice, but on the Dole-Vallorbe line up to 2.5 km has been allowed in many cases, and even more in a few instances. It should be noted also that over several lengths, totalling some 32 km of single line, the track is laid on RS type reinforced concrete sleepers, provided with insulated fittings

(1) Actually, this line of demarcation is purely indicative and made for convenience: it will be seen that even in the installations dealt with in the first part of this article, electronics play some part, as in the track circuits and directional single line interlocking; while electro-magnetic relays perform some functions dealt with in the second part, in connection particularly with the control of the indicating lamps on the illuminated diagrams.

designed to suit this equipment. (The insulation resistance per kilometre of the track circuits concerned has been found to be within acceptable limits and up to the present adjustments have been made and maintained without difficulty.) The musical frequency type track circuit has been used throughout, fed at four different frequencies, 300, 850, 1 500 and 2 000 cycles, to obtain the desired alternate difference between one circuit and the next. This type of equipment, developed in connection with the electrification of the lines in the north-east of France, where several hundred kilometres have been equipped for some years, has already often been described and therefore need not be further mentioned here.

2. **Single line interlocking.**

On a single line fitted with automatic signalling, something additional must be provided to prevent two trains from being started simultaneously from the stations at the ends of a section. This is known as single line interlocking, or directional control.

More precisely, this means that a form of reciprocal interlocking is provided between two stations, which we may call G_N and G_{N+1}, which effectually prevents a train from being sent from G_N towards G_{N+1} unless the two following conditions obtain, namely :

1) the signals at station G_{N+1} giving access to the single line are proved to be at danger; and

2) the last train sent by that station (G_{N+1}) has completely cleared the section between the two.

To ensure that these conditions are fulfilled, voice frequency currents are employed modulated completely or not at all at a rate of 20 impulses per second (frequencies $f1$ and $f2$ for the direction G_N to G_{N+1}, and $f3$ and $f4$ for the reverse direction G_{N+1} to G_N). These currents are *normally* being emitted as the interlocking circuit is based on the principle of either station being free to obtain possession of the section at any time provided it is unoccupied.

The effect of the frequency $f1$ is to energise at G_{N+1} a so-called « totalising » track relay, while frequency $f2$ fulfils a like function at station G_N. Frequency $f3$ serves to energise at G_{N+1} a « direction relay » and $f4$ does the same thing at G_N.

The frequencies $f1$ and $f3$ are transmitted over one pair of wires in the cable and $f2$ and $f4$ over the other; these pairs form one of the outer quads.

Such an arrangement offers the maximum advantages from the point of view of the traffic working as each of the stations knows at any instant what the condition is of the directional control. (As a rule, in such installations this is not the case and it is necessary therefore to oblige the stations to enquire of each other as to the situation obtaining by making a « test » or proving signalling, by using their apparatus.)

From the technical point of view, however, this method of working necessitates the taking of special precautions to ensure that there is no risk of disturbing currents giving rise — if only for an instant — to the creation of stray currents able to release any locking

irregularly. Such an assurance has been obtained, and this risk to all intents and purposes eliminated, thanks to the use of electronic devices producing currents sufficiently distinctive that no confusion with a stray current is to be feared in actual practice. The transmitting and receiving modulated frequency equipment comprises for each half section — that is for one end of a single line crossing place — two modulated oscillators on the one hand and two decoding receivers on the other.

Figure 2 shows an interlocking assembly for directional control used on part of the Dole-Vallorbe line; it will be seen that it incorporates electronic apparatus.

3. **Electric power signalboxes at intermediate stations.**

This equipment is designed in such a manner that the line can, should circumstances require, be operated from station to station without any control from the central point, for the following reasons :

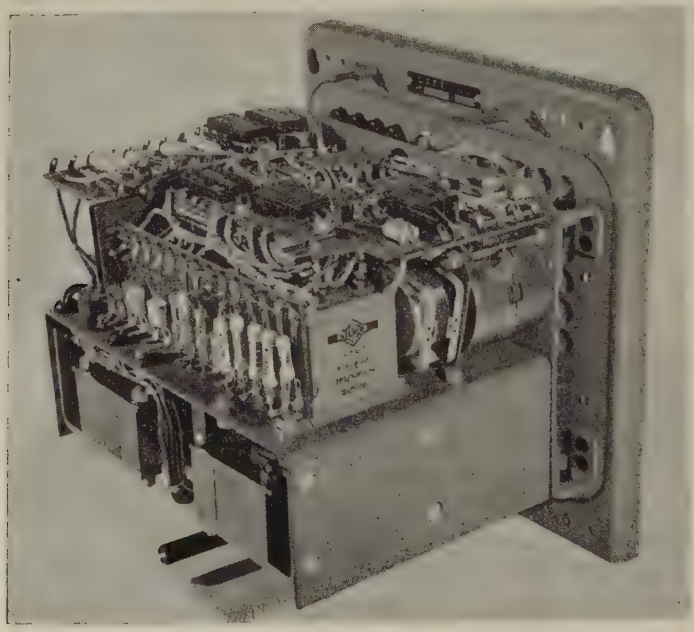

Fig. 2. — Single line directional interlocking unit.

the line between Dole and Vallorbe will not be equipped throughout with centralised control for some time yet and it was on its central portion between Mouchard and Frasne that it was of consequency to apply, as a first step, this centralising of the route setting. In any case to equip the entire line would have given rise to considerable delay and provisionally it could be worked, in the

absence of a central controller, by exchanging messages between stations.

The intermediate stations are therefore so arranged that they can be worked locally by means of electric push-button ([1]) type interlocking apparatus or be remotely controlled from a central point, This illustration also shows the indications given on the illuminated diagram at the central control point relative to this particular station. On this appear the various signals, track circuits and such supplementary indications, as may be required (Z.Ap. or approach locking

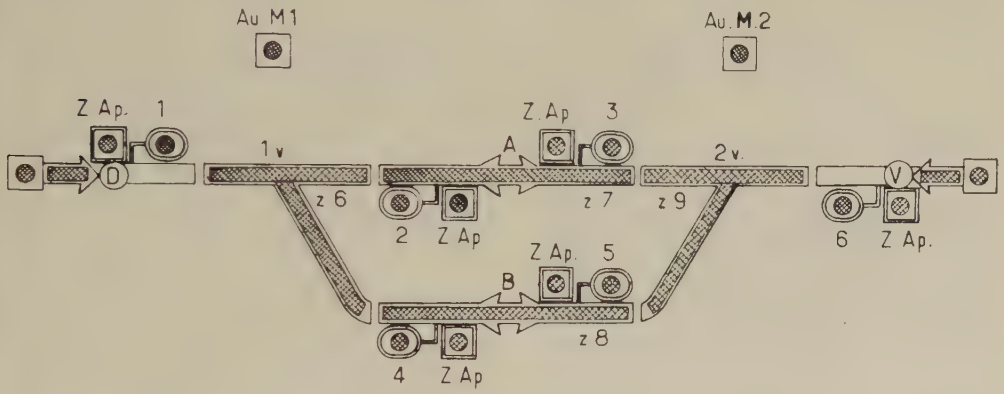

Fig. 3. — *Dole-Vallorbe.*
Arrangement of equipment at an intermediate station (signals, track circuits, shunting releases, etc.).

the station staff then not being required to do anything.

A diagram of the signalling layout of a station is given in figure 3. There is one loop track with the corresponding sets of points and the signals required to meet the operating programme.

section, Au.M. or shunting release, for giving permission for local movements to be carried out at the station, etc.).

This form of intermediate station equipment follows the latest arrangements designed by the S.N.C.F. with the object of simplifying the layout as much as possible. These make a large use of what are called safety type relays, constructed to very detailed and careful specifications and subjected to very severe tests. Their working is such that no special precautions in the way of proving and detecting are needed, such as are absolutely necessary in the case of relays not offering such guarantees of reliable working. The introduction of such proving arrangements into the

([1]) The S.N.C.F. type of « push-button » signalbox is so arranged that a route becomes set up by the use of a single button and not two (entrance and exit buttons). If the use of two buttons is suitable in a number of cases, it is, generally speaking, less satisfactory than operation by a single button. This latter arrangement indeed gives the maximum saving of time and eliminates all interference where more than one signalman is on duty. In addition, it is the only method to use when the most up-to-date methods, using pre-selection and storing of routes, are adopted.

circuiting complicates it considerably and gives rise to the risk of other kinds of failure occurring, while retarding their finding and removal. On the Dole-Vallorbe line these relays, although smaller and less expensive than the type of equipment used generally hitherto, possess safety characteristics which have been very strictly verified; it is possible to be certain that, if no current is flowing in the coils, there is no risk whatever of an armature remaining made. One can similarly be sure that the various relay contacts cannot occupy positions with respect to each other susceptible of creating irregular operation of the installation.

This perfecting of the working of the safety type relays confirmed by long and extended operation in service, has allowed of using layouts presenting the maximum of simpleness : figure 4 shows the principle diagram of the electric equipment of the intermediate station when same is being operated locally. (In reality, this represents half a station, forming a unit set of apparatus repeated throughout the line.)

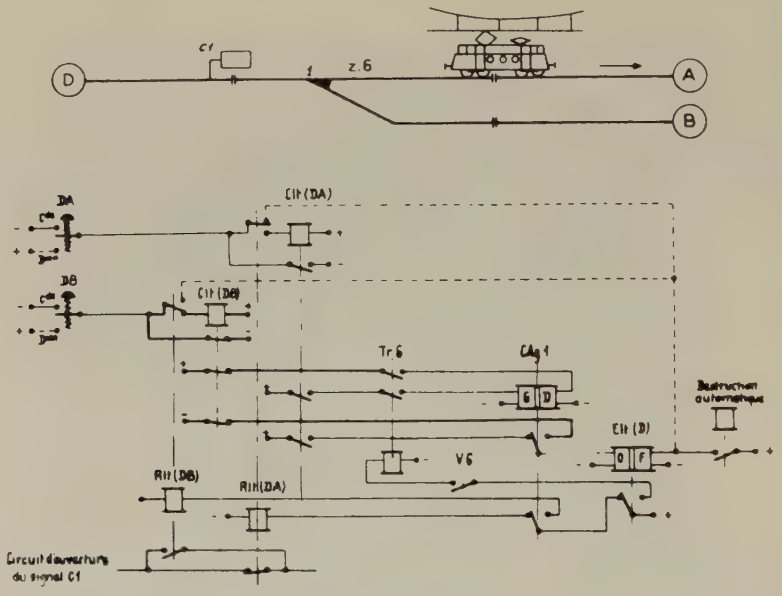

Fig. 4. — *Dole-Vallorbe.*

Diagram showing the principle of the circuits used at an intermediate station.

In the diagram in figure 4 is seen a button applying to the route DA and another to the route DB. In the condition shown, route DA has been set up and route DB pre-selected. The train is passing over route DA and immediately the track circuit section 6 at points 1 becomes clear, these points, through the

coming into action of the pre-selection, will become reversed automatically ready for route DB (1). (Contact V6 of the track relay for section 6 will become made, which will set the point control relay CAg1 in the « right hand » position. As soon as these points have moved completely into this position, the route relay RIt DB will become energised, which will permit signal C1 to clear for route DB, provided of course that all necessary proving and detecting circuits are properly closed).

This very simple and well functionning type of apparatus follows the standard pattern (2) of which nearly a hundred of specimens of very varying size are in service on the S.N.C.F. lines. All safety requirements are fully provided for at site. As regards the pre-selection, this allows of only one route, conflicting with the one set up, being stored in readiness.

We shall see, however, when considering the centralised control arrangements, that while the station arrangements remain as before and particularly that all safety requirements are provided for locally on site, independently of remote control, a step forward has been made as regards the storage of route controls, since the traffic controller is able to establish several such in readiness.

It may also be pointed out in connection with this that in the case of the electric control and proving of the points, a specially designed arrangement has been adopted which is very simple and offers some special advantages. The working does not involve, as is the case with many earlier or existing circuit arrangements, the carrying out, each time the points are operated, of a succession of operations in which the dependent relations between various appliances impose special conditions, the final proving, or return indication, not being given until the whole cycle has been completed. In the Dole-Vallorbe installation, each operation is carried out for itself, and results in fully valid and effective return indications, an arrangement which gives, owing to the quality of the equipment used, the advantage of simplicity while reducing to the minimum the risk of failures, and of their consequences also, should one occur.

4. Supply of power to lineside equipment.

In the ordinary well known forms of signalling, the production of electric power and its distribution along the line represents an important percentage of the total cost involved. Special sub-

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(1) It will be seen that with this apparatus a pre-selected route becomes set up immediately the one previously set up has been cleared by a train. (This is in fact, considering the form of the apparatus, the simplest thing to arrange and it is found to give complete satisfaction.) In the case of the *Dole-Vallorbe* line, however, the arrangement for the stored route controls is different and is especially suitable to the conditions obtaining; it will suffice for the moment to say that it is the train itself, as it approaches, which causes a stored route to become set up. Such a route, therefore, becomes set up in front of the second instead of behind the first train. (See further on the reference to the « conditions of release » or « bringing into effect » in the case of such a stored control.)

(2) This type of signalbox is designated for short the P.R.S. (« Poste tout relais à transit souple. »)

stations must be equipped, with standby generating sets, while cables must be laid specially to feed the various items of equipment located along the line.

Electrification using current suitable for industrial purposes enables these costs to be considerably reduced. The signalling installations are in large part fed from the 50 cycle supply of the electrified line, (including the electronic track circuits which generate on site the special frequencies applicable in each case). At intervals, along the route, transformers are provided connected to the traction circuit to reduce the voltage of 25 000 V to 380 V, this latter is then distributed along the line.

The distribution of this current between two points of connection to the traction circuit does not necessitate the laying of a special cable. It is effected over the one used for general purposes, employed simultaneously for the signalling and short distance telephone communication and also the transmission of power. All the conductors in this cable are polyethylene insulated, giving high di-electric properties and excellent transmission qualities, even at high frequencies. The centre quad is screened by an aluminium band or tape and those arranged round it are protected by steel tape armouring covered by a P.V.C. sheath. The central quad serves on the one hand to transmit the remote controls and return indications by which the installation is operated from the traffic controller's office and on the other hand to distribute power by a phantom circuit.

PART TWO.

CONTROLS AND RETURN INDICATIONS FOR STORED ROUTES.

1. Storage of routes : operating programme.

Centralised traffic control of which many examples exist throughout the world, is as a rule arranged to meet the following programme : the signals and points requiring to be controlled and located along the line are actuated by small keys, sometimes working in association with code transmitting buttons, operated at the central point where the control apparatus is placed. This working involves the sending, for the particular set of points or signals concerned, under the form of coded currents (with the aid of relays) of the orders necessary to control such apparatus. Once this has been effected the return proving indication is transmitted back from the equipment and becomes shown on the illuminated diagram at the central point. This means that each control must be prepared in advance and the points and signals put in the correct position before the train concerned is due to pass.

The centralised traffic control between Houilles and Sartrouville, the operating point for which is at Saint-Lazare station in Paris, was installed in this form in 1933 and its working has ever since been satisfactory.

In 1949, the S.N.C.F. put into service between Blaisy and Dijon on its Paris-Lyons line, C.T.C. equipment which differed in important respects from its predecessors : the control of the signals and points was no longer effected

individually; such working on the contrary is not seen in this installation. All controls are effected by route buttons, which transmit all the orders required, greatly facilitating the task of the operator at the central point. The principles applied in this case are the same as those adopted for the S.N.C.F.'s standard type of power signalbox, which means that it is possible to pre-select one route control conflicting with another, or in short to store one such control, under the conditions mentioned above when describing the elementary half-station equipment for an electric power installation (fig. 4).

The S.N.C.F. has now had a lengthy experience of the storage of route controls in its many electric power signalboxes of modern design. This has enabled it to effect a large concentration of controls, while simplifying the layouts of the stations, reducing to a minimum the number of signalmen concerned and greatly facilitating their work.

It appeared that for the Dole-Vallorbe line — for the Mouchard-Frasne section to begin with — it would be of advantage to develop further the benefits of this automatic working by allowing the central traffic controller to set up in advance the controls for a number of routes corresponding to the expected train movements. The first of these would take effect on the ground, the others being held in readiness, or stored. After the passage of the first train over the route first set up, the latter would become released and the following train would set in action for itself the setting up of the second route, which itself would be released by the passing of that train, and so on.

Let us now see in more detail how events take place from the moment when the traffic controller sets up the route controls until the moment when they become effective on the ground.

The controller has controlling and proving equipment at his disposal (see figure 5 showing the desk panel and figure 6 giving in more detail the actual controlling portion with illuminated diagram above).

The *control items* comprise spring return push-buttons working on the step-by-step, or succession, principle, which means that a first depressing of a button sets up the particular control concerned and the next one cancels it.

The following are the types of buttons used, distinguished by their respective functions :

— individual route buttons (four per single line station);

— combined route buttons (three at a single line station, for the up and down overtaking movements, crossing movements to left or right, and up and down through running movements);

— shunting release button, for permitting shunting to take place;

— stage or serial button (one for each stage in the series of stored route controls and per station) allowing of the route setting buttons becoming connected (for individual or combined through route controls) to a particular stage in the series of operations, or of permitting the combined crossing or overtaking route buttons becoming connected to this stage or one above it;

— holding button (one per half station) allowing of the automatic coming into operation of the stored controls being postponed, while still allowing the controller to use stages one to four, as well as the so-called zero stage, which the corresponding storage arrow indicators.

The working of the stage buttons and of the holding and shunting release buttons is proved by a lamp located in each button.

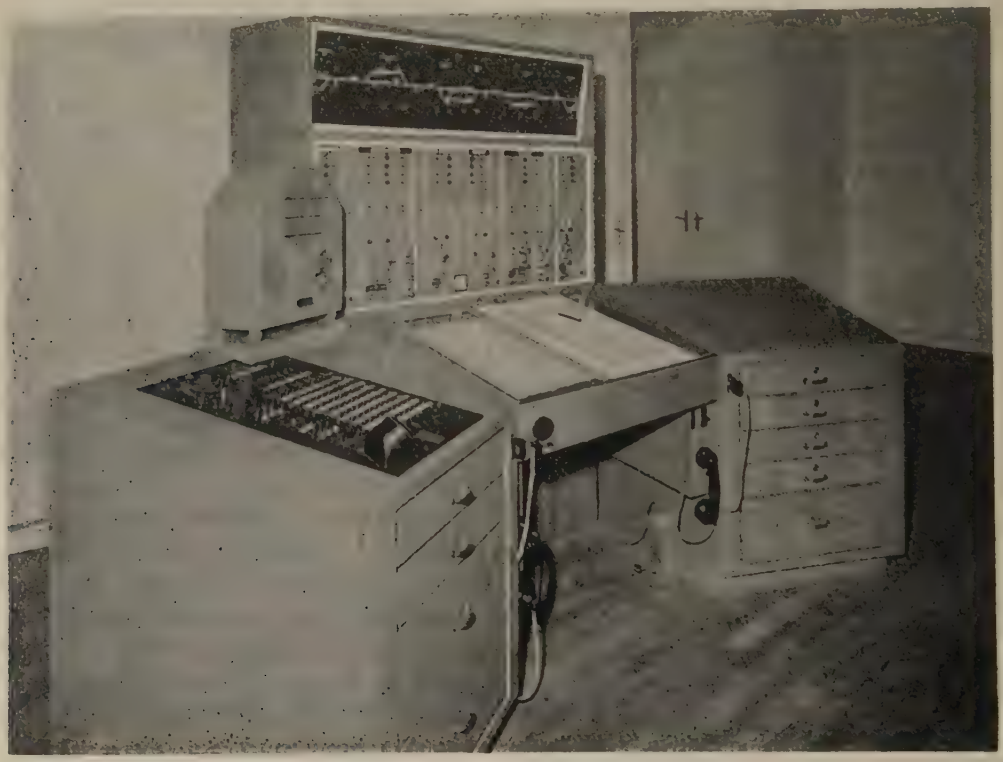


Fig. 5. — Controller's remote control desk panel with illuminated diagram.

is the normal one, referring to movements being effected on the ground;

The two first types of button have two working positions, the three others one only.

The route buttons (individual or combined) have no indicating lamp; their action is proved by the lighting up of

As regards the *controlling elements* on the panel, the traffic controller has lamp indications to help him, some located on the working position of the panel, the others on the usual well known track diagram.

The « working » portion of the assembly (see figures 6 and 7; the latter

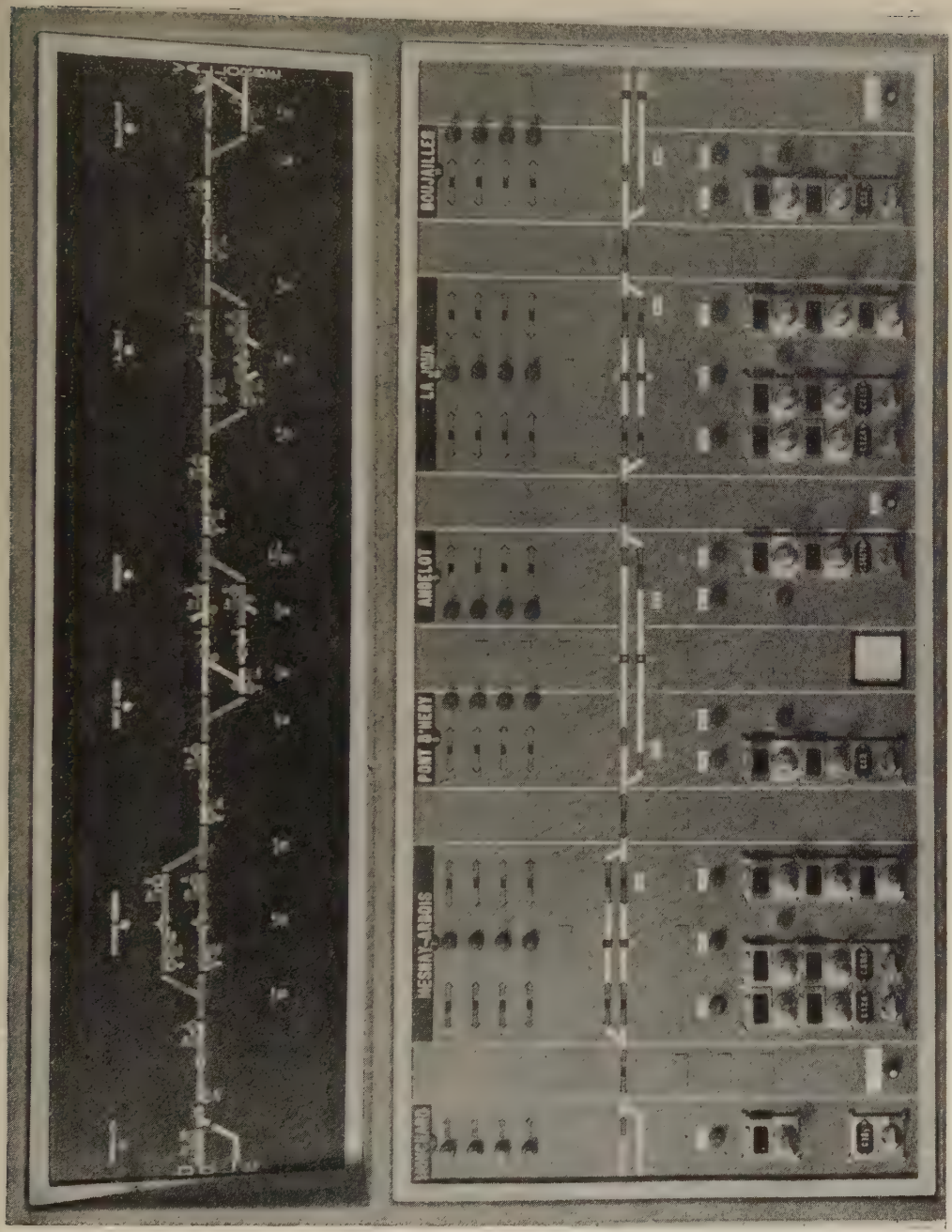


Fig. 6. — Enlarged view of operating portion of panel and illuminated diagram.

showing the engraving of a section relating to an intermediate station) comprises the control buttons already referred to with a certain number of visual indications showing in representative fashion the various stored route controls (in stages one to four) or actually in force on site (zero stage).

These indications are in the form of horizontal arrows (green always denoting a direct and yellow a diverging route) each line representing a stage so far as stages one to four are concerned.

The indications relating to the zero stage are arranged in a form representing the actual layout of a station but in simplified fashion :

— the illumination of these indications is steady or flashing according to whether the route concerned has been effectively set up on the ground or its controls have merely been stored in readiness;

— the colour changes to red when the section of track concerned becomes occupied;

— the appearance of the illuminated arrows is related also to the « direction » of traffic over the routes concerned and they become dark again as soon as the route they represent is released.

In addition, there is an indicator showing the condition of each platform line; this shows red whenever the section concerned is occupied whether any route has been set up or not.

The zero stage has also an indicator referring to the section between each two stations, also in the form of an arrow which becomes lighted when a directional single line control relay is energised. The colour of this arrow is :

— white if the section between the starting signal of the station concerned and the home signal of the adjacent one is unoccupied;

— red if there is a train or vehicle in such section.

The particular arrow lighted at any given moment shows the direction being taken by the movement in question.

It is to be noted that the accidental de-energisation of a track relay or unusual occupation of a section will not cause these arrows to light up.

Finally, the zero stage comprises additionally between the stations and in the stations themselves, special visual indicators arranged to show the timetable number of the trains running or standing in the sections involved.

The illuminated diagram itself carries indicators forming a continuous line of light, but normally dark. This diagram shows for each station the condition of the track circuit sections through the points, and also of the signals, the approach control sections, whether permission for shunting to take place has been given or not, and the state of the directional interlocking between stations.

Normally, the indications on this diagram are not lighted up except those referring to the signals, the approach control sections and the shunting releases.

When a route becomes set up, the track circuit section indicators become illuminated in white, as also those repeating the position of the points as soon as the return indication from them is received. In like manner, the directional indicator relating to the section

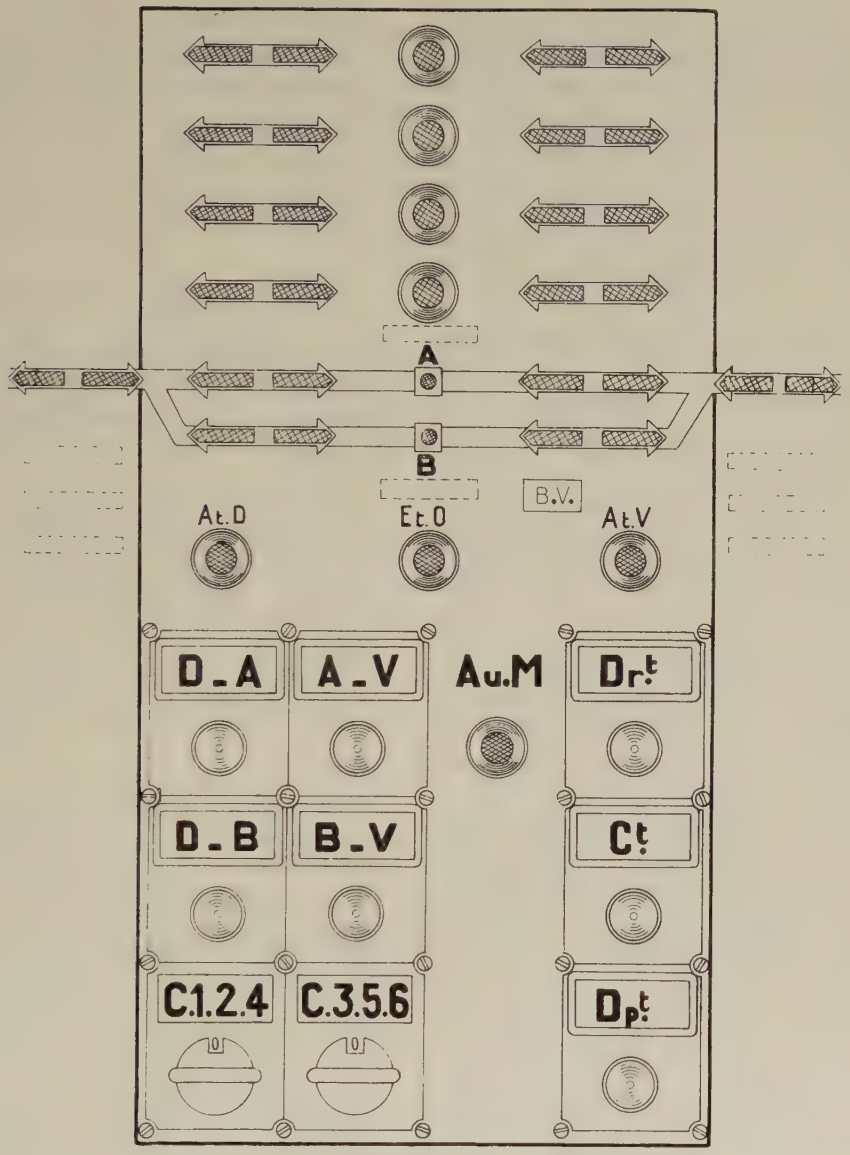


Fig. 7. — Engraved panel cover plate for an intermediate station.

At the bottom are placed the route buttons :
— individual (D-A, A-V, D-B, B-V);
— combined (through direct run, crossing, overtaking);
as well as the switches for placing signals to danger and the shunting release button.
At the top, the arrows indicate what route controls are stored (at the four upper stages, or levels) or have been carried into effect on the ground (bottom stage).
In the centre, on the vertical and horizontal lines, are the stage and holding buttons.

between stations lights up, also in white, immediately the relevant directional control relay becomes energised. This last mentioned becomes red directly the section between the starting signal at one station and the home signal at the next in advance becomes occupied.

In addition and independently of any other condition, the indicators for the station track circuit sections show red. The lighting of a section on the trailing approach side of a set of points is selected by the position of the tongues.

Whenever the section of line between the home signals of adjacent stations is occupied, an additional indication, located between the arrows, shows red, whatever the direction of movement concerned.

A button known as the « test » allows of all the indicators being lighted which refer to the condition of the points or the track circuit sections, having regard to the position of the point tongues or state of occupation of the lines.

The conditions governing the working of the storage of the route controls relating to a signal box of the S.N.C.F's P.R.S. type, or all-relay interlocking with sectional route release, are as follows :

A. *Storage of a control* (stages one to four).

The storage of a control A at station X in stage n is effected by actuating successively the button applying to stage n and the one corresponding to the control A at station X.

It is possible to store up to two routes only in the one stage at a given station, at the rate of one route per half station, and independently of the counting conditions subsisting between them.

In consequence, a direct through run involves a single stage only while an overtaking or a crossing movement has its controls stored in two successive stages.

In order to register a crossing or an overtaking movement in stages n and $n + 1$, it suffices to actuate the button relating to stage n if such registration is effected by using one of the combined buttons.

On the other hand, if it is desired to register the same route controls by means of the individual route buttons, it becomes necessary to actuate in turn the buttons of stages n and $n + 1$, so as to store each of the other corresponding routes.

B. *Working of the stage push-buttons* (stages one to four).

The stage buttons serve to allow the controls exercised by the route buttons (individual or combined) to be connected to the particular stage desired.

When one of these buttons is actuated the lighting of the corresponding proving lamp indicates that operation thereafter of the route buttons will act upon this particular stage. It is to be observed that the actuation of a stage button remains without effect if the button referring to the zero stage has been made use of. Moreover, the actuation of a stage button is effective only if no transfer to that stage is taking place, or to the two superior ones.

Reciprocally, the actuation of a par-

ticular stage button prevents any transfer to that stage from being effected.

To cancel the effect of operating a stage button, all that is necessary is to actuate it a second time.

C. *Carrying a stored control into effect.*

1) The storing of a route control is indicated by the lighting of an arrow pointing in the direction to be taken by the train over the route; this is coloured green if the direct route is concerned and yellow if a diverging one is involved.

2) The storing of the controls for a crossing or an overtaking movement is shown by four lighted arrows representing the four routes successively necessary to effect such a movement, these being again green or yellow according to whether a direct or diverging route is in question.

3) The arrival of a train brings about, if this has not already taken place, the transfer to stage one of the route control for the direction involved stored in the lowest stage. This only takes place, however, if all the routes concerning the half station in question have been released on site.

4) The stored control on becoming transferred to a stage in this manner, brings about the transmission of the corresponding remote control and itself becomes finally cancelled as soon as the return indication is received proving that the actual route has been duly set up on site.

5) As soon as a storage stage concerning all the stations of a section of single line becomes entirely free, in consequence of such setting in operation of the stored controls, it becomes at once re-occupied by those contained in the stage above. This transference takes place from one stage to another, in such a way that after a lower stage becomes free, all the stored controls contained in those above move down one stage.

D. *Arrangements peculiar to the zero stage.*

The zero stage is indicated by illuminated arrows arranged in simplified geographical form, showing the actual routes set up on the ground.

The actuation of the zero stage push-button takes precedence over the stage buttons, that is to say that its operation prevents the controls stored in the upper stages from coming into effect, and so allows the equipment on the ground to be remotely controlled direct, eliminating any action on the part of the buttons on the storage stages.

After the zero stage button has been actuated, the operation of an individual or combined route button referring to an up or down through running movement will transmit the remote control code relating to the route or routes concerned.

Figure 8 gives an example of the appearance of the return indication arrows referring to an overtaking movement; it will be seen how, for twelve successive situations of two trains, the indications relating to the station change. An overtaking movement, for which the controls have been stored is shown to take place on the ground, this being followed in the storage apparatus by the controls for a crossing movement.

E. *Operation of the holding buttons.*

The actuation of a holding button cancels the conditions under which, at the half station concerned, the stored route controls are carried into effect and consequently serves to hold or lock up such controls at that place until this button is actuated once more.

The operation of a holding button has no effect on the stage buttons. It is in consequence possible to effect all the operations relating to storage (either setting up or releasing of route controls) after a holding button has been actuated, and of course to carry out any direct remote control operations at zero stage.

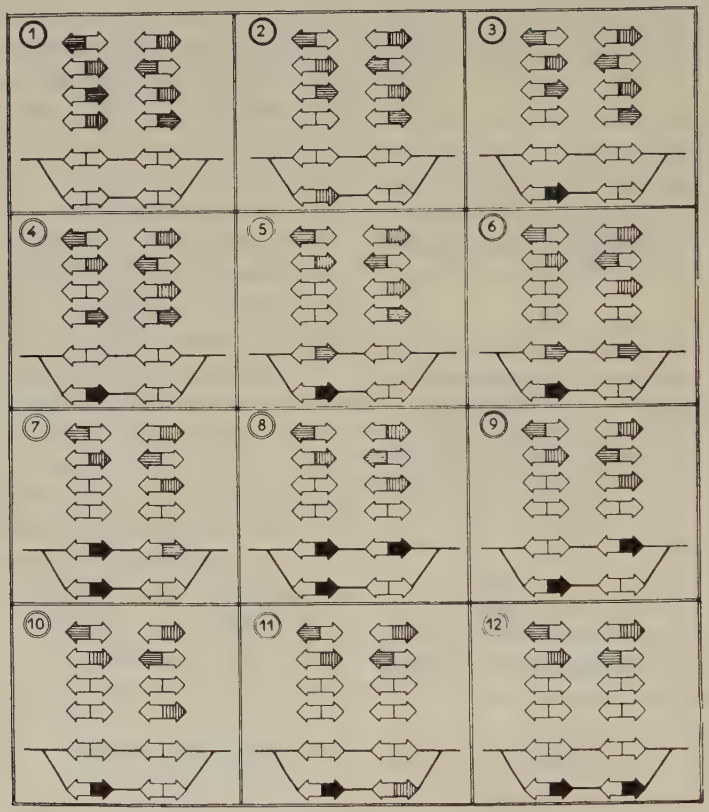


Fig. 8. — Example of the arrow indications exhibited in the case of an overtaking movement.

(1)	Normal condition, before any route is set up.
(2)	Route set up for the first train to take the loop line.
(3)	Arrival of the train in the loop line.
(4), (5), and (6)	Setting of the direct route for the overtaking train.
(7), (8) and (9)	Train runs through on the direct line.
(10), (11) and (12)	Train departs from the loop line.

F. *Cancellation or release of a stored control.*

Cancellation of a control A, stored in stage n at station X is effected by actuating in succession the button for stage n and the one for the control A, for such station.

The cancellation of a combined control (for a crossing or an overtaking movement) concerning stages n and $n + 1$ is effected by operating in turn the button for stage n and the one referring to the combined control concerned.

In addition, the manual cancellation of a control registered in stage n must not have the effect of causing the place left vacant in that stage by such action to become occupied by whatever control happens to be stored in stage $n + 1$, if at this moment stage n is free at all the stations. Such transference only takes place, if the case requires it, after cancellation by repetitive action of the operation previously effected on the button of the stage concerned.

G. *Substitution of a stored control for one already established.*

If, in the case when a route control has been stored in stage n, after actuation of the relevant stage button, a button relating to a route different from the one stored is made, this second route will replace the first if it concerns the same half-station.

Similarly, after the actuation of a button for stage n, and if controls are already stored in stages n and $n + 1$, substitution of controls will take place in these stages should a combined route button be actuated (for a crossing or overtaking movement) corresponding to a storage requirement differing therefrom.

H. *Conditions under which stored controls are carried into effect.*

The conditions under which stored controls become effective are produced by the occupation under certain conditions of the approach track circuit sections in rear of the home signals at the entrance to the routes concerned.

I. *Special arrangements at limiting stations equipped with mechanical or electro-mechanical signalboxes.*

Such signalboxes do not come under the control of the central traffic controller except for such movements as concern the single line itself, permission to enter thereon being then given by that official.

The permission given by him becomes stored, the condition under which it becomes effective answering to a particular programme in which only the setting up of the directional control to take possession of the single line section comes in question.

J. *Cancellation of a control which has already become effective.*

Manual cancellation of a route already set up on the ground is effected, after actuating the zero stage button, by operating a second time the control button applying to such route. If, however, the approach track circuit section is already occupied, it is necessary first to operate the switch for setting the home signal concerned to danger in case of emergency.

2. **Storage of route controls; technical details (« programme apparatus »).**

The storage of the route controls is effected by an electronic device. This offers the following advantages peculiar to this new technique : high operating speed, considerable capacity, having regard to the number of combinations to be catered for in carrying out the working programmes concerned, and robust construction in consequence of the elimination of moving parts.

This apparatus, of very novel character, for such a service, will be described later, without however giving every detail of its actual working which would exceed the limits of the present article.

First of all, we will review the elements constituting the different parts of this electronic programme apparatus.

It makes use of components currently used in electronic equipment, such as germanium diodes, junction transistors, bi-stable or throw-over devices known as « flip-flops », oscillators, multivibrators, « gates », diode matrixes and electronic amplifiers.

In figure 9 is seen a schematic diagram of the centralised control as installed between *Mouchard* and *Frasne*. At *Mouchard,* the central control point, is the programme apparatus. Here are located the transmitting assemblies for the remote control (marker, distributor, coder, transmitter or emitter, and coupler). The remote control codes, sent out over the cable, are received on the ground by the remote control receiver units.

The arrangements are similar as regards the return indications. Out on the ground, the return indication codes are transmitted from the emitter units concerned and pass over the cable to the receiving assembly dealing with the return indications at the central control point.

The heart of the installation, that is the equipment in which the route controls become stored, called the programme apparatus, comprises various essential components which can be listed as follows :

— the items associated with the control and stage buttons and the storage components;

— the items performing the carrying into effect of the controls with their transference and the transference by line or single line section;

— the components associated with the repetitive action, the cancelling or the substitution of one route for another;

— the components associated with the zero stage, or the operations effective at the moment;

— the distributor;

— finally, the circuit, relating to any rythmic action, composed of multivibrators which synchronise the operations in the various circuits.

The control buttons actuate a throw-over device equipped to deal with each movement. This in turn sets in position the companion device dealing with the storage action concerned.

The transfer circuit controlling the bringing into effect of a control has a connecting diode matrix and intermediate amplifiers; the line transfer circuit is formed of « gates » of the « and » type connected with the throw-over units concerned with the stage storage.

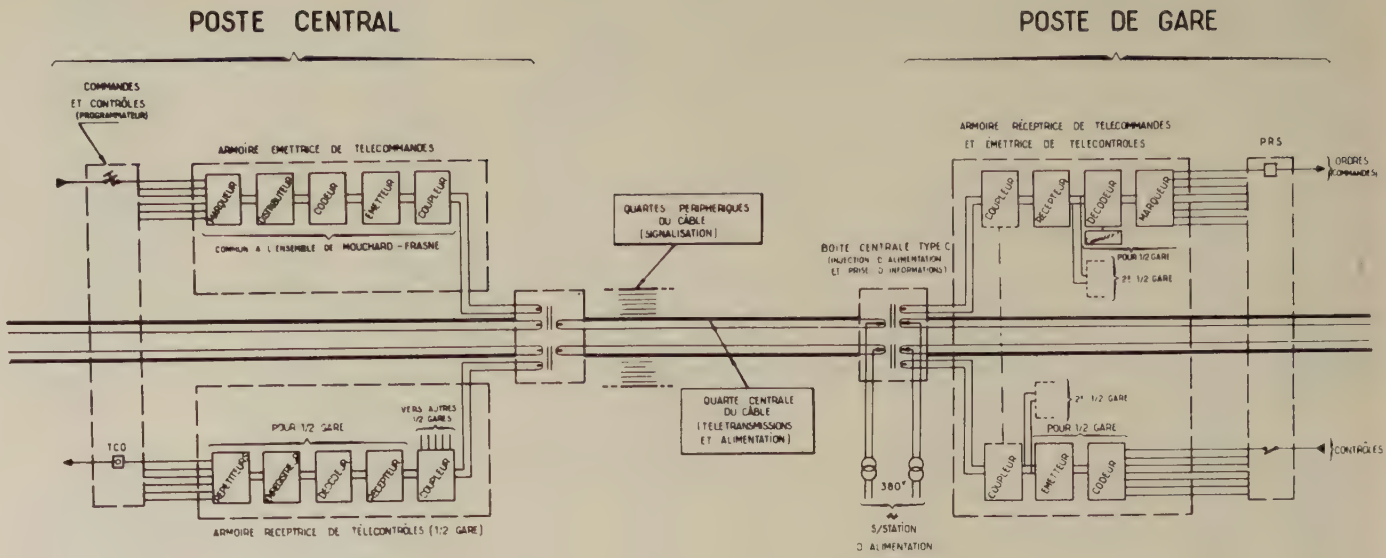


Fig. 9. — Schematic diagram of the C.T.C. worked from Mouchard.

Explanation of French wording :

Poste central = apparatus at central control room. — Poste de gare = apparatus at a station. — Commandes et contrôles = controls and return indications. — « Programmateur » = programme apparatus. — T.C.O. = illuminated diagram. — Armoire... télécommandes = group of equipment for sending remote controls. — Marqueur = marker. — Distributeur = distributor. — Codeur = coder. — Emetteur = emitter. — Coupleur = coupler. — Commun... Frasne = common to the equipment and working between Mouchard and Frasne. — Pour 1/2 gare = for half a station. — Vers autres 1/2 gare = to the remaining half stations. — Répétiteurs = repeaters. — Enregistreur = recorder. — Décodeur = decoder. — Récepteur = receiver. — Quartes... (signalisation) = outside quads of the cable (for signalling). — Quarte centrale... alimentation = centre quad of the cable (for transmission of remote controls, return indications and power feed). — Sous/station d'alimentation = power feed substation. — Boîte... informations = central junction box, type C (for power feed and making tests). — Armoire... télécontrôles = group of equipment for receiving remote controls and sending out return indications. — PRS = relay interlocking signalbox. — Ordres (commandes) = controls for the equipment on the ground. — Contrôles = return indications.

The circuit associated with the repetitive action is composed essentially of a double entry diode matrix, the polarisation of a horizontal bar or path leading to the freeing of a vertical one, in relation with an « or » type of « gate » (cancelling circuit).

The zero stage, to which under certain conditions the route remote controls become transferred acts as the operative stage, and is being continuously scanned by the distributor. In this stage are concentrated all special controls, such as the emergency placing of signals to

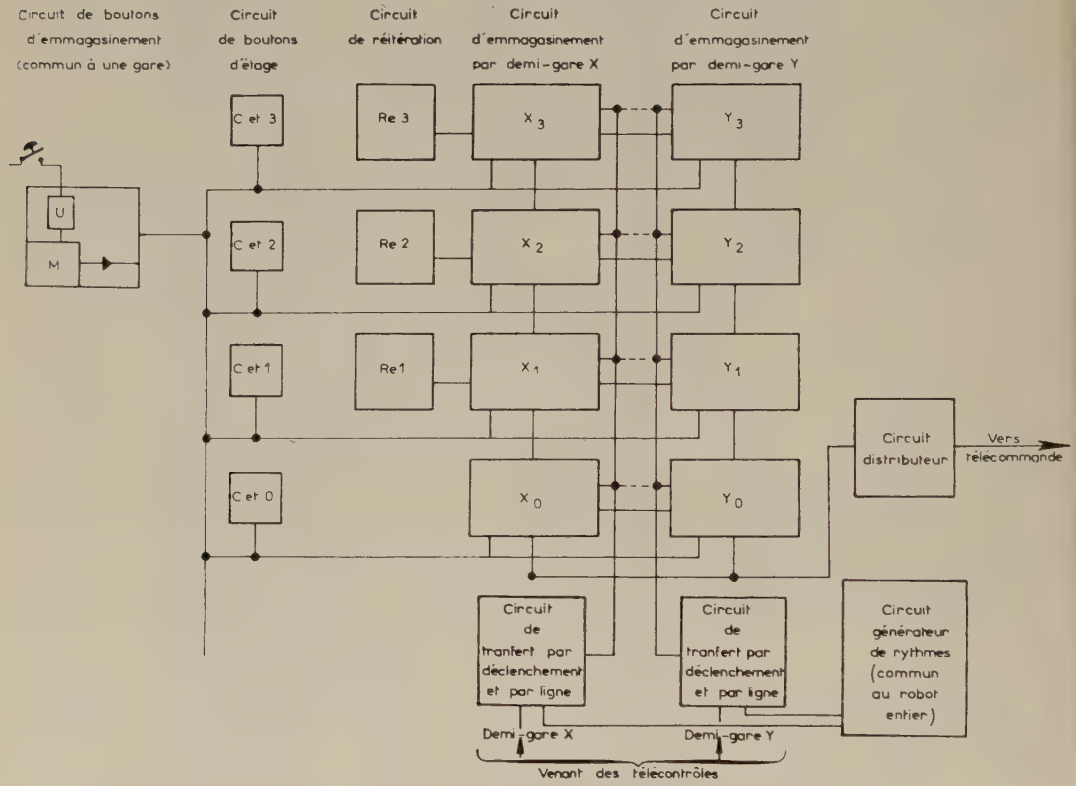


Fig. 10. — *Mouchard control room.* Storage of route controls.

On the left, the route control button; on the right, the sending out of the control itself.

Principal intermediate items of equipment; storage circuit per half station; transference circuit (per act of setting in action or per line); distributor circuit (which sends out the remote controls in order of urgency).

Explanation of French wording :

Circuit... (gare) = storage route button circuit (common to one station). — Circuit... d'étage = stage button circuit. — Circuit de réitération = repetitive action circuit. — Circuit... X = storage circuit per half station X. — Circuit... Y = storage circuit per half station Y. — Circuit distributeur = distributor circuit. — Vers télécommande = to the remote control. — Circuit... ligne = circuit for transference of controls, per act of setting in action and per line. — Demi-gare = half station. — Circuit... entier = impulse generating circuit (common to the entire equipment). — Venant des télécontrôles = from the return indications.

danger and transmission of shunting releases. In this stage also are received the indications reflecting the condition of the equipment on the ground.

The function of the distributor is as follows : the storage of route controls for a length of route can cause several controls to arrive simultaneously in the zero stage. The distributor performs a constant cyclic scanning operation covering all stations along the line, at the same time sending the remote controls operative at a given moment to the relevant stations. (It deals as a matter of first priority with any station where the setting of signals to danger in emergency is called for).

The schematic diagram illustrating the string of the route controls (fig. 10) shows how the essential functional components are arranged : storage control circuits, stage button circuits, repetitive action circuits, and the circuits dealing with the storage per half-station with

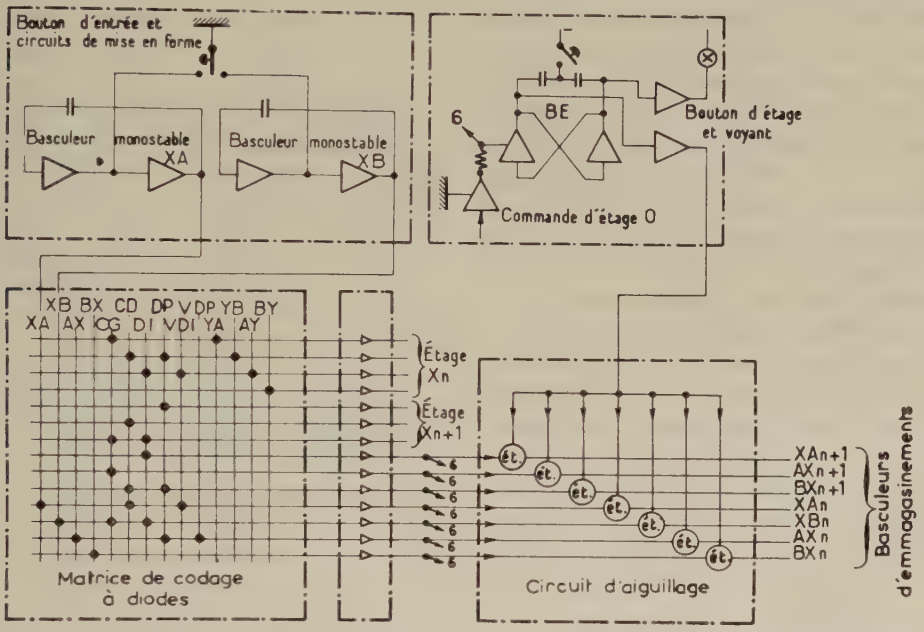


Fig. 11. — Storage of route controls. Route and stage buttons. Coding matrix and circuits for distribution of the controls.

Detail of the working of the programme apparatus : route control button and stage button. connected on the one side to the coding matrix (route and stages) and on the other to the distributing circuit (connection with the storage « flip-flop » devices).

Explanation of French wording :

Bouton... forme = main initial button and setting circuits. — Basculeur monostable = monostable change-over device. — Bouton d'étage et voyant = stage button and lamp indicator. — Commande d'étage 0 = control of the zero stage. — Matrice... diodes = diode type coding matrix. — Stage Xn = stage Xn, etc. — Circuit d'aiguillage = distributing circuit. — Basculeurs d'emmagasinements = storage throw-over devices (« flip-flops »).

transfer and distribution circuits, and the rythmic pulse generator.

By way of example, there is given on figure 11 in connection with the storage of route controls, as far as the route and stage buttons are concerned, the coding matrix and the paths by which the effects are transmitted. Each route button is associated with a throw-over device; actuating the first results in the setting of the second. Each such device feeds the vertical bar or path in the diode matrix and via its horizontal ones, this matrix directs the control signal originated by the button towards the storage throw-over unit for the stage involved (case of a simple route). This operation is placed under the control of a stage button and a path finding circuit. This last is formed of « gates » of the « and » type which open if the following conditions are fulfilled :

— a signal arrives from a route button via the throw-over units and coding matrix;

— a signal arrives, originating with the actuation of a code button via the intermediate throw-over unit BE.

The part played by the distributor in the working of the programme apparatus has been dealt with above. Without entering into a detailed description, we may say that it comprises the following interconnected components :

— the seeker, or hunter, which finds the wanted stations;

— the seeker or hunter which finds the remote controls applicable at a given moment;

— the combiner.

The two first named correspond to the functions of the distributor already mentioned.

As to the combiner, this is a device which intervenes in the operations in the following manner : it has eight positions and at each one, through a combination matrix, it can send controls out over the associated circuits.

Let us assume the station seeker to be at position n (that station n requiring to receive a remote control) the combiner to be at position 1 and the seeker which finds the controls to be in any position (not being obliged to agree with the remote control stored for the station n).

Let us now see what operations take place with respect to the different positions of the combiner :

1) the combiner asks station n whether or not it has a remote control operative at the moment (first question);

2) the combiner registers the reply received from station n to the question asked under 1) above (first reply).

If the reply is in the negative, the combiner instructs the station seeker to move to the position $n + 1$, but if in the affirmative, it holds it at position n;

3) the combiner then ascertains if there is any emergency remote control in operation for putting signals to danger as an urgent matter at any station, (including n) for such a control could have come into force while the combiner was moving from 2) to 3) above (second question);

4) the combiner registers the reply received to the question given under 3). Let it be assumed that no urgent remote

control is in question at any station but that an ordinary one is operative at *n* (second reply);

5) the combiner now ascertains whether the remote control seeker is in a position indicating that such a control is registered for station *n* or not (third question);

6) if the seeker is in the remote control position, registered with respect to station *n*, it brings the transmission of the control concerned into operation (third reply). If the seeker is not in a position corresponding to the remote control which is registered for station *n* it asks the combiner to move to position 7);

7) as the seeker is not in the position relevant to the registered remote control, the combiner now repeats the question given in 5) above, and then moves on to position 8), while the seeker itself moves forward one step;

8) should the seeker in so moving reach the position corresponding to the registered control, this latter will be sent out at position 6) of the following cycle. If, however, the seeker has not located the control, the above cycle will be repeated until this is effected except that if, in the course of the seeking process, the combiner itself comes upon an emergency control for setting signals to danger.

The combiner comprises moreover some positions which set three throw-over devices in operation and can give them eight different positions. These eight positions polarise in eight different ways the eight horizontal paths of the combination matrix. This has ten vertical ones, transmitting the orders to and receiving the replies from the associated sub-assemblies.

The passages of the current impulses take place in conformity with the operations effected by the combiner.

The above particulars are of course insufficient to form a detailed account of the electronic route storage equipment, but they will give an idea of its general structure and of its main operating principle. This electronic arrangement has been proved to meet all the requirements of the traffic operating programme in the best manner. (And, let it be emphasised, it was a question of an entirely new problem to meet for which no ready-made electronic solution was available). The very design of the arrangement allows of a great saving of time in operation while the fact that the equipment contains no moving part serves to ensure great regularity of working and reduces the maintenance required.

3. **Transmission of the controls.**

The transmission of the controls for the C.T.C. system is effected over the two pairs of conductors in the quad specially allocated to them, one pair to the controls and the other to the return indications. The frequency band used for the *Mouchard-Frasne* installation covers approximately the telephonic voice-frequency range. When the centralised control becomes extended to the whole *Dole-Vallorbe* line, the frequencies used will be increased up to about 5 000 cycles.

Transmissions are effected in groups of

five (or four) impulses (positive or negative) of a duration of 20 milliseconds, separated by « off » periods, two successive groups being separated by an interval of 40 milliseconds.

These groups of impulses are utilised in the following manner :

— for the remote control, since these are coded, each group forms a code;

— for the return indications, the transmissions being effected by cyclic scanning, each impulse is allocated to an indication (positive or negative) and thus a group of five impulses transmits five indications.

For the remote controls, the (intermittent) emission of current comprises two groups of impulses :

— the first, containing five impulses, constitutes the code for selecting the particular « satellite » outlying location concerned (capacity is $2^5 = 32$ codes);

— the second, containing four impulses, constitutes the code for selecting the particular item of apparatus to be operated at such location (capacity is $2^4 = 16$ codes).

For the return indications the (permanent cyclic) emission of current comprises eight groups of five impulses, or forty return indications (positive or negative) representing one cycle, the performing of which is constantly repeated with a 120 milliseconds interval between two cycles. Each cycle thus transmits the complete set of indications, modified or not with respect to the preceding set. If the outlying location requires a capacity of more than 40 indications a supplementary 40 indication channel is used in addition.

Each pair of line conductors is fed by :

— one frequency (common to all the outlying locations) in the case of the pair carrying the remote controls;

— as many frequencies forming independent transmission paths as there are groups of forty controls (in practice one frequency to each half-station) in the case of the pair carrying the return indications.

The impulses, positive and negative, are obtained by modifying the carrier frequency by plus or minus 30 cycles. These carrier frequencies are in the normal harmonic scale, spaced 120 cycles apart. It takes about 400 milliseconds to transmit one remote control and less than two seconds to transmit a group of 40 return indications.

The equipment used is largely electronic in character and makes considerable use of semi-conductors. However, on the receiving side, the final end item of apparatus is formed of eletro-magnetic relays, functioning under conditions similar to those applicable in the case of like components in « all-relay » signalboxes.

CONCLUSION.

The electrical equipment installed on the *Dole-Vallorbe* line offers a number of characteristics rendering it worthy of attention from both the operating and engineering points of view ([1]).

([1]) It should be noted that, in addition to the installations described in the present article, trials have been begun of a method of communication between a fixed point and the engine crews, using two parallel line wires, the arrangement being such as to be easily applied whatever the nature of the ground or surroundings and offering in addition a means of providing the supplementary facility of communicating between fixed points themselves situated along the line.

Care has been taken to utilise the best principles and practice applied already to the construction of safety relays of the electro-magnetic type and thanks to the high degree of performance obtained, the circuit arrangements have been simplified, the regularity of operation improved, and the maintenance rendered easier.

Parallel with this, new and specially designed adaptations of electronic equipment to signalling installations have been perfected. In particular, by using suitable assemblies of components, the fruit of considerable tests and experience, transistors have been applied to signalling, bringing with them valuable facilities and advantages, such as rapidity of operation, robust construction, long life, great saving of space — especially acceptable — and in addition, the possibility of meeting much more completely the requirements of the traffic working.

It is the fact that these new installations, in consequence of the high degree of automation incorporated in them and the rapid transmission of remote controls and return indications, have enabled electrically operated train services to be handled satisfactorily on a line formerly double but of which a great part is now single line. Not only has the cost of equipping the line been thus very greatly reduced, but the maintenance and staff charges have been also, compared with what would have been required with the well known forms of apparatus hitherto used. Perfected under the difficult conditions obtaining on a line where the climate can be severe, this equipment provides the answer to a problem often met with on the railways, to which on the *Dole-Vallorbe* line an original solution has been provided, utilising the latest engineering developments met with in the industrial world.

[625 .215]

The riding properties of bogie vehicles.

Theoretical prediction of railcar and locomotive riding performance as an aid to the rationalisation of bogie design,

by J. L. KOFFMAN,

(*The Railway Gazette*, Nov. 27, 1959; Dec. 11 and Dec. 25, 1959.)

So much has already been said about the effect of oscillations on the human body that the following comments are presented with some reluctance. However, the question of suspension characteristics is an ever important subject, and references to « hard » or « soft » suspensions and to « spring rates » abound. Yet what is « hard » and « soft » here, what is the line of demarcation, and what is the significance of the spring rate so readily proffered and obviously cherished by many designers ? And again, what are the characteristics of a good or a bad suspension ? In fact, what is it we are trying to achieve as far as our designs are concerned, and how are we to assess their performance in simple terms which will also serve to facilitate further design improvement ?

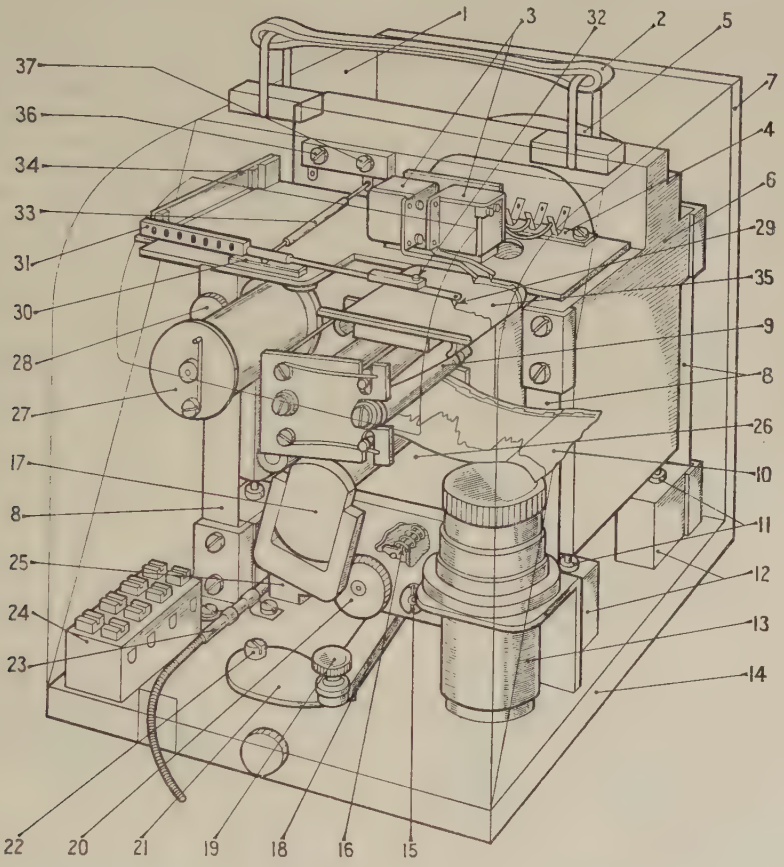
As far as the assessment of the effectiveness of the suspension is concerned, this should, if at all possible, be expressed by a single value embracing the fundamental factors in a manner permitting ready interpretation by designers. It should be in the form of an index, or a figure of merit (or demerit), the quoting of which should, among other things, conjecture in the minds of those concerned an image of the vehicle behaviour. The relevant data should be recorded and evaluated without undue difficulty if use is to be made of the procedure for rapid and reliable performance assessment, and comparison — a matter of particular importance in connection with vehicle development.

The investigations concerned can often be effectively limited to a relatively simple procedure which can provide much useful information. The tests considered here were devised to obtain information of direct and immediate use to designers frequently working against time and quite unable to wait for comprehensive reports. Apart from this, complicated equipment requires too many hands and too many man-hours for its upkeep, occasionally making testing so time consuming and expensive that it is frowned upon or dispensed with altogether. Use should be made of commercially available equipment as far as practicable. This equipment should permit ready testing during normal schedule runs, while an important point in favour of simpler instrumentation is also that often it ensures direct recording permitting an immediate appreciation of the results. This is a valuable feature as tests can be quickly repeated or extended if the influence of certain factors is doubtful or their importance is appreciated in a new light. The amount of information which can be obtained by relatively simple means suggests that more attention should be devoted to this approach, particularly as not unduly expensive instruments are commercially available to facilitate it. Here the use of only one such instrument will be briefly considered, this being a simple accelerometer and displacement recorder which can be used within the more important ranges mostly encountered in service.

A representative instrument.

The Askania Universal Vibrograph, figure 1, representative of instruments of this type, is based on the spring-mass principle. The mass 6 which weighs about

13 lb. is supported by four leaf springs 8 which are secured to the blocks 12. The spring 16 permits adjustment of the zero position of the stylus 29 with aid of the screw 20. The natural frequency of the instrument is determined by the springs 8 and 16, while the displacement of the mass 6 is limited to about $^3/_8$ in. Damping



1. Housing;
2. Carrying strap;
3. Mark recorders;
4. Connector block for mark recorders;
5. Bellows;
6. Inert mass;
7. Rear panel;
8. Leaf springs;
9. Rubber roller;
10. Recording tape;
11. Distance screws;
12. Blocks;
13. Battery;
14. Base plate;
15. Air nozzle;
16. Helical spring;
17. Winding key;
18. Locking bar;
19. Button for locking bar;
20. Knurled screw for zero line adjustment;
21. Disc;
22. Disc screw;
23. Flexible control cable;
24. Terminal block.
25. Supporting block;
26. Spring drive;
27. Supply roller;
28. Knurled button;
29. Stylus;
30. Guide;
31. Recording lever;
32. Adjustment screw;
33. Connection rod;
34. Leaf spring joint;
35. Recording table;
36. & 37 Adjustment screws.

Fig. 1. — The Askania Universal Vibrograph is a useful instrument for exploring vehicle vibration patterns. It can also be used to determine acceleration and brake performance.

is by the action of the rubber bellows 5 mounted between the mass 6 and the rear panel 7, the necessary damping being achieved by the air forced from the bellows through the nozzle 15. The recording mechanism 29-37 records the displacement of the mass 6 with the aid of a stylus 29 on wax-coated paper 10, the mass (housing) being coupled to the recording lever 31, both being operated from a dry cell battery 13. The instrument can be used to record horizontal or vertical oscillations. With a natural frequency of about 5 cycles per sec. and a damping factor of about 0·5, it is suitable to record accelerations of up to about 5 cycles per sec., while displacements are recorded at higher frequencies, although it is, of course, possible to determine

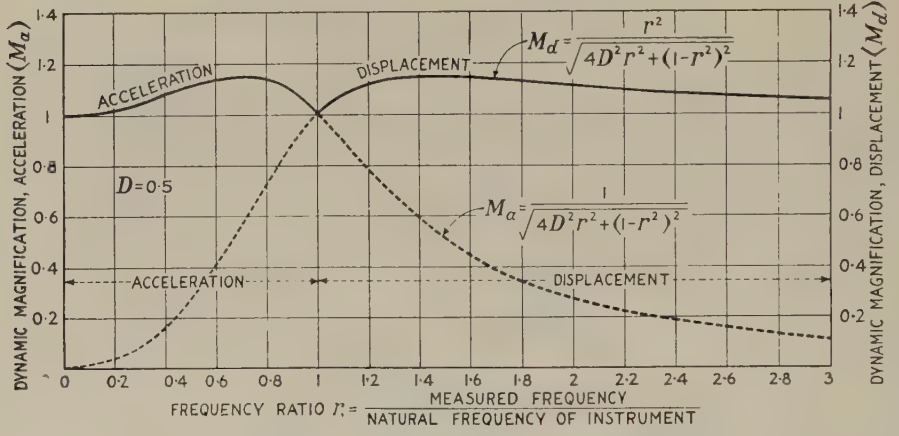


Fig. 2. — The results obtained at frequencies in excess of the natural frequency of the vibrograph can be corrected with the aid of the above curves.

by the rod 33. The lever magnification can be readily adjusted to 4 to 1, 10 to 1, or 20 to 1, the range of acceleration being ± 0·01 to 1 g., ± 0·004 to 0·4 g., and ± 0·002 to 0·2 g respectively, while the range of displacements is ± 0·05 to 5, ± 0·02 to 2, and ± 0·01 to 1 mm respectively. The spring drive 26, which is started and stopped by the cable 23, drives the rubber roller 9 which moves the paper from the roll 27 over the recording plate 35 and thence out through a slot in the housing. The driving spring runs for 2 min. The rubber roller can be fitted on to the slow or fast driving shaft, the paper feed speeds being 10 mm per sec. and 30 mm per sec. respectively. The paper tape is 50 mm wide, but only 40 mm are used for recording, the remaining 10 mm being reserved for the time records (marked at 1 sec. intervals) and for an event marker, displacements or accelerations within either frequency range, assuming sinusoidal oscillations. The complete accelerometer has a size of 6 in. by 7 in. by 9 in. and weighs 26 lb.

Examples of use of curves.

The records can be evaluated with the aid of the curves, figure 2, when considering accelerations recorded at frequencies below the natural frequency (5 cycles per sec.) of the instrument (frequency ratio $r < 1$); and displacement at $r > 1$. The curves can also be used to determine accelerations for frequencies at $r > 1$ and displacements at $r < 1$. The relevant procedure is illustrated below for a scale of 1 mm = 0·8 ft./sec.^{2} and 5 mm = 0·25 mm displacement.

Example 1.

Measured frequency $f = 2$ cycles/sec.

Frequency ratio $r = 2/5 = 0{\cdot}4$.

Recorded acceleration amplitude $e =$ 6 mm.

Dynamic magnification (fig. 2) : $M_d =$ 1·08.

Actual acceleration 6 (mm) × 0·8 (ft./sec.²)/1·08 = 4·45 (ft./sec.²) = 0·1385 g.

Without correction the above value will be increased to 4·8 ft./sec.² or 1·495 g, which, considering the somewhat random nature of vehicle records, should be quite adequate for the purpose of overall performance evaluation.

Example 2.

Recorded frequency $f = 10{\cdot}5$ cycles/sec.

Frequency ratio $r = 10{\cdot}5/5 = 2{\cdot}1$.

Recorded displacement $e = 7$ mm.

Dynamic magnification (fig. 2) $M_d = 1{\cdot}1$.

Actual displacement = 10·5×0·25/1·1 = 2·38 mm (as compared with 2·62 mm without correction).

Example 3.

Recorded frequency $f = 10{\cdot}5$ cycles/sec.

Frequency ratio $r = 10{\cdot}5/5 = 2{\cdot}1$.

Recorded acceleration amplitude =7mm.

Actual acceleration $b = e\,x^2 = e\,(2f)^2$, where $e = 2{\cdot}38$ mm. (Example 2).

$$b = 2{\cdot}38\ (2 \times 3{\cdot}14 \times 7)^2;$$
$$= 4\,600 \text{ mm/sec.}^2;$$
$$= 15{\cdot}1 \text{ ft./sec.}^2 = 0{\cdot}47 \text{ g.}$$

Example 4.

Recorded frequency $f = 2$ cycles/sec.

Frequency ratio $r = 2/5 = 0{\cdot}4$.

Recorded displacement $e = 6$ mm.

Dynamic magnification (fig. 2) $M_d =$ 0·185.

Actual displacement $e = 6 \times 0{\cdot}25/0{\cdot}185$ = 8·12 mm.

The evaluation of oscillation records merits careful consideration. The results can be presented in the form of plots of predominant accelerations or frequencies, as a function of vehicle speed, and in this form would be helpful when comparing the riding qualities. Such information would not be entirely adequate because the results of tests presented in this manner would not permit evaluation in terms of human reaction so important with footplate crews, not to mention passenger vehicles and occasionally management-carrying locomotives. Extensive work on the sensitivity of the human body to oscillations were carried out in general terms by Reiher and Meister (1), and investigations relating to aircraft conditions were pursued by Constant (2) and Coermann (3). Road vehicles were considered by Olley and Janeway (4) and more recently by Dieckmann (5), and the effect of oscillations on railway passengers formed the subject of extensive investigations due to Sperling (6). All investigators agree that the human body is most sensitive to frequencies of about 4 to 6 cycles/sec., and also that the range of frequencies of importance on this subject does not stop there but extends into a range of 20 and 30 cycles/sec. and higher. As far as rail vehicles are concerned, the work due to Sperling is the clearest and most reliable so far. In common with some other workers in this field, Sperling found that depending upon the frequency range, the human body is sensitive to acceleration d^2y/dt^2, the jerk d^3y/dt^3 (acceleration per unit time) or the work done on a unit mass by the oscillation, i.e. $y d^2y/dt^2$ (amplitude × acceleration). With e as amplitude and f the frequency, the maximum acceleration is given by $e\,(2\pi f)^2$, the jerk by $e\,(2\pi f)^3$ and the work done by $e^2(2\pi f)^2$. Sperling also found that the ride value of a vehicle is determined by the relation ce^3f^5, i.e. the product of (work done) × (jerk) = $e^3(2\pi f)^5$. The sensitivity S of the human body is expressed as :

$$S = C\sqrt[10]{e^3 f^5}$$

and the actual ride index as :

$$V_r = 2{\cdot}7\sqrt[10]{e^3 f^5 F(f)}$$

where V_r is a numerical value, e (cm) the amplitude, f (cycles/sec.) the frequency, and $F(f)$ a correction factor allowing for the

effect of frequencies. Since the acceleration is given as $b = e(2\pi f)^2$:

$$V_r = 0{\cdot}896 \sqrt[10]{(b^3/f)F(f)}$$

where b (cm/sec.^{2}).

The magnitudes of the correction factor are obtained for vertical oscillations from :

$F(f) = 0{\cdot}325f^2$ for 0·5 to 5·9 cycles/sec.
$F(f) = 400/f^2$ for 5.9 to 20 cycles/sec.
$F(f) = 1$ for above 20 cycles/sec.

while for lateral oscillations :

$F(f) = 0{\cdot}8f^2$ for 0·5 to 5·4 cycles/sec.
$F(f) = 650/f^2$ for 5·4 to 26 cycles/sec.
$F(f) = 1$ for above 26 cycles/sec.

The V_r values are numbered from 1 to 5, the numbers signifying :

1 — very good;
1·5 — almost very good;
2 — good;
2·5 — almost good;
3 — satisfactory;
3·5 — just satisfactory;
4 — tolerable;
4·5 — not tolerable;
5 — dangerous in service.

Usually vehicles do not maintain constant ride values even when running at constant speed over identical track, so that the final V_r value is the result of evaluations obtained over the entire run in terms of ride value magnitudes and the number of times these were encountered :

$$V_{r_t} = \sqrt[10]{\frac{n_1 V_{r_1}{}^{10} + n_2 V_{r_2}{}^{10} + \ldots + n_n V_{r_n}{}^{10}}{n_1 + n_2 + \ldots + n_n}}$$

If the oscillations are composed of a low frequency base line resulting in V_{r_1} and superimposed high frequency oscillations giving V_{r_2}, then :

$$V_{r_t} = \sqrt[10]{V_{r_1}{}^{10} + V_{r_2}{}^{10}}$$

This method of evaluation is particularly useful as it provides an index which has a very definite meaning in terms of amplitude and acceleration or velocity (displacement) values, and these can be readily interpreted by the designer in terms of component action. A further advantage is that the magnitude of the index rises very slowly with speed, and sometimes it remains practically constant so that the vehicle performance can be indicated by a single value. And last but not least it is possible to calculate this value in advance on the basis of the vehicle design characteristics and certain simplifying assumptions relating to the amplitudes of excitation. The latest German standard coaches are stated to maintain values of about 2·2 to 2·4 in the vertical and 2·3 to 2·6 in the lateral plane, respectively, while values as low as 2 are claimed for the TEE trains. Generally values of 3 to 3·25 are considered as just acceptable for coaches as compared with the upper limit of 4 to 4·25 for wagons.

The magnitudes of V_r values corrected in accordance with the above data are plotted in figure 3 in a form applicable for evaluation of the records considered here. The method is suitable for evaluating vehicle riding qualities in terms of time spent and results obtained, particularly as the latter can be readily interpreted in terms of direct use (amplitudes, accelerations and frequencies) to vehicle designers. The results considered here, although obtained « at random » are more representative of the vehicles and of the operating conditions, and as such are more suitable for general assessment than tests carried out over the same stretch of track at a number of speeds, particularly when analysed on a statistical basis for a great number of conditions typical as to track, speed and load (9). It should also be mentioned that road tests on symmetrical vehicles can be carried out by one man in one day, analysed by the same man in one week and the findings plotted and reported in about two weeks' time.

The tests considered here were carried out by placing the accelerometer on the cab floor, approximately in line with the driver's seat, and the oscillations recorded for at least

15 sec. whenever steady speeds were maintained on straight track. Note was also made of the motor or generator current as particularly with axle hung motors, the torque can have an effect on the action of the primary springs. Generally the mean value of accelerations was determined by dividing the record into a number of magnitude ranges in steps of 1 to 2 mm depending on the scale, counting the peaks in the various ranges for a given length of record and using this data to determine the mean acceleration encountered at the speed concerned. It might be mentioned that a method sometimes used elsewhere to determine the « most frequently encountered » average value is to ascertain the magnitude of peak values which, over a distance of 200 metres, is reached or exceeded five times. This determination is carried out with the aid of a straight edge moved upwards along the record until it touches five peaks or its position comes below four peaks, just touching the fifth. Whilst on the straight, the tendency for the wheels, i.e. vehicle, is to run up against the right-hand rail just as frequently as against

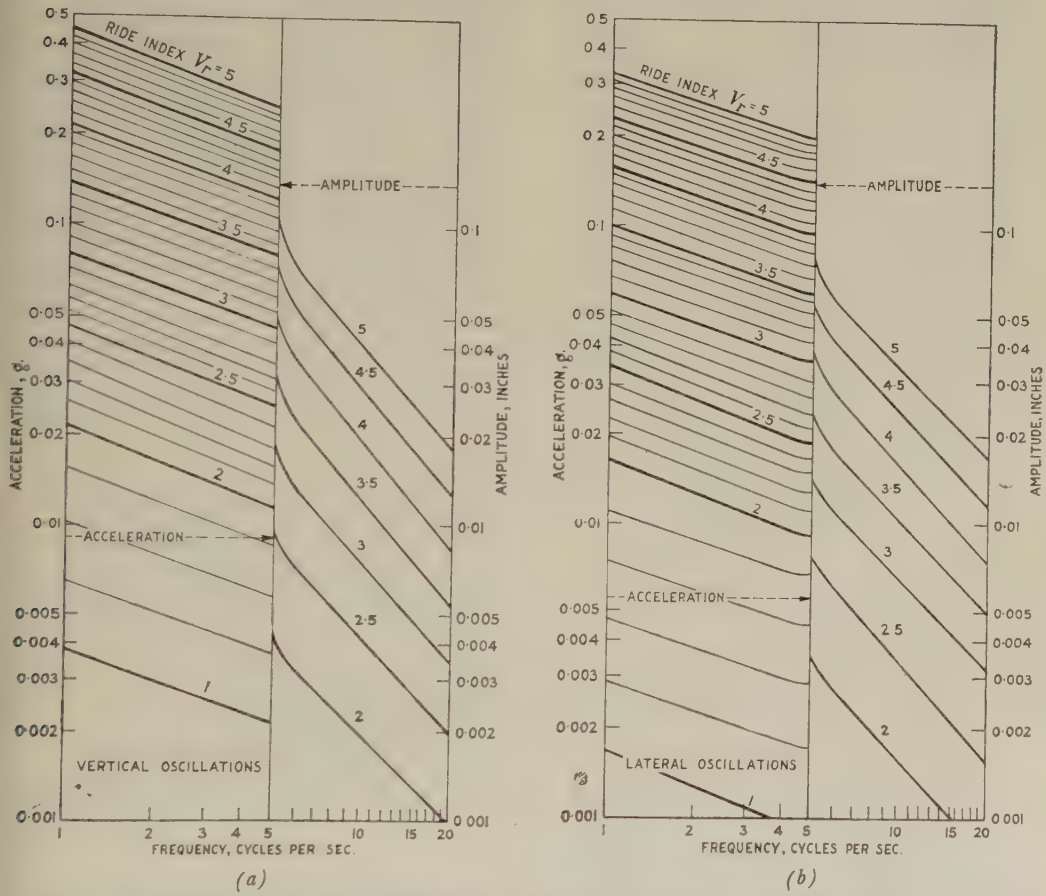


Fig. 3. — The values of ride indices plotted as a function of frequency and acceleration up to the natural frequency of the vibrograph. Above this frequency the index values are plotted in terms of frequency and displacement.

the left-hand one, in curves the tendency is towards one-sided running and consequently here the significant average acceleration value is the one encountered not more than 10 times over a distance of 200 metres.

Masking effects.

The determination of frequencies is more difficult and time consuming. Many records show a rather random pattern over most of their length and the natural frequency only occasionally appears as a clear record not masked by higher frequency oscillations. Here the previous calculation of the probable order of the fundamental frequencies will be of considerable assistance to an observer trained, by experience, to separate the fundamental frequency from the masking effects. The correct frequency analysis is particularly important with lateral oscillations where the frequency of excitation is significant of the sinusoidal frequency of the wheelpath down the track. Previously purely theoretical considerations suggested that the frequency of the sinusoidal oscillations due to a « free » wheel set is given as :

$$f_1 = \frac{v}{2\pi}\sqrt{\frac{\gamma}{rs}} \text{ (cycles/sec.)}$$

and that with two axles kept strictly parallel to each other and at right angles to the track:

$$f_2 = f_1\sqrt{1+\left(\frac{l}{2s}\right)^2} \text{ (cycles/sec.)}$$

while for three axles kept strictly parallel to each other and at right angles to the track :

$$f_3 = v/2\pi\sqrt{\frac{r}{\gamma}\left(s+\frac{l}{2}\cot\psi\right)} \text{ (cycles/sec.)}$$

$$\text{where } \sin\psi = \frac{2s}{l^2+4s^2}\left(\frac{l}{2}+\sqrt{l^2+3s^2}\right)$$

v (ft. per sec.) is the vehicle speed, γ the tyre connicity (i.e. $\gamma = 0{\cdot}05$ for 1 in 20), 2s the distance between the rolling circles of the wheels (for standard gauge $2s = 4{\cdot}94$ ft.) and l (ft.) the bogie wheelbase (7).

Thus on a purely theoretical basis the use of two parallel axles should result in an appreciable reduction of the lateral frequency, and in the case of three axles the gains would be somewhat less. However, in practice it was found that with conventional bogie axle guides the frequency did not rise directly as a function of speed, but at a slower rate, while the use of more positive guides did not ensure the theoretically predictable improvements (8). These results related to coaches and railcars and were to some extent attributed to the mass action of the relatively heavy body. This trend was so far not confirmed for bogie locomotives with which the frequency, although rising less rapidly with speed than f_1, was found to be directly proportional to speed. However, the data plotted in figure 4 for bogie locomotives of conventional design suggests that the pattern also applies here, i.e., the

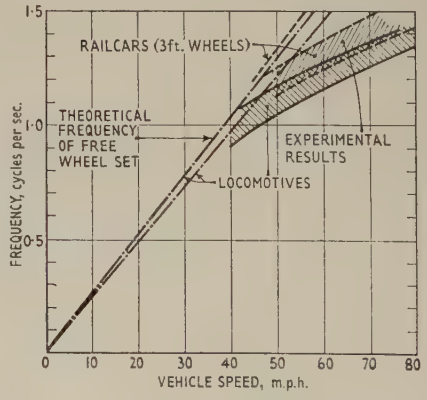


Fig. 4. — The theoretical and experimental values of the lateral frequency due to wheel motion.

frequency increments are reduced as the speed increases, whilst on the other hand at low speed the frequency is higher than the theoretical value. As far as design is concerned, the significance of this dependence is apparent when considering « resonance » speeds of the body nosing on swing links as well as swaying, and also when

considering the rotational-torsional oscillations of the body, all of which are excited in the first instance by bogie hunting.

Vehicle body oscillations.

The oscillations originating at the rail, in addition to exciting the suspension system also excite oscillations of the vehicle body, particularly if the pitching frequency of the bogies happens to be at or near the natural frequency of the body. It should also not be overlooked that the natural frequency of the track under the vehicle is frequently of the same order as the natural frequency of passenger vehicle bodies. These can be regarded as a uniform beam freely supported at two points; the bogie centres. In the case of coaches, the range of fundamental vertical frequencies lies between about 10 and 16 cycles per sec., although values as low as 6 cycles per sec. have also been encountered while with bogie locomotives the frequencies are often of the order of 8 to 12 cycles per sec., the actual magnitude depending upon the overall body length L (ft.), the modulus of elasticity E (t per sq. ft.), the moment of inertia I (ft.^{4}), the mass per unit length m (t sec.^{2}/ft.)/ft. and a factor C depending on the ratio l/L, where l (ft.) is the length between bogie centres, as well as upon the arrangement of body support. For modern coaches the ratio l/L varies between about 0·67 and 0·74, and within these limits C can be represented by a straight line, the values varying between 3·12 and 2·71 respectively. With these data it is possible to determine the frequency f since :

$$f = \frac{C}{L^2}\sqrt{\frac{EI}{m}} \text{ (cycles/sec.).}$$

The value of m relates to the body shell and underframe only, and generally is of the order of 0·0035 to 0·0055 (t sec.^{2}/ft.)/ft. The range of the natural frequencies (vertical) of modern coach bodies is about 6 to 20 c.p.s. This data can be readily obtained with the aid of a suitable rotary unbalance oscillator, the power consumption of which has been previously ascertained over its speed range. The resonance frequency and stiffness of the structure is then obtained from the peaked rise of power required to drive the unbalance (10). The natural frequency of the body can also be gathered from the records of a vibrograph placed on the floor while running the vehicle over wedges.

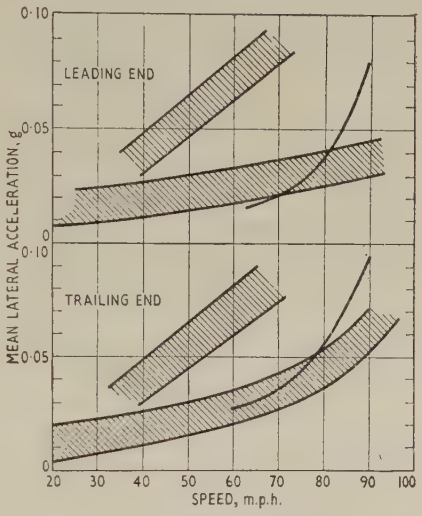


Fig. 5. — Mean values of lateral acceleration measured in the cabs of a number of bogie locomotives. The range of higher values is significant for locomotives with which higher frequencies predominate.

The lateral accelerations depend upon vehicle speed, the actual magnitudes depending on the pattern of the sinusoidal motion, the wheel flange to rail clearance, the bogie wheelbase and distance between bogie centres and the relation between the latter and the length of the wave pursued by the wheels or bogies (8). Representative mean values ascertained for modern bogie locomotives running in normal schedule service are indicated in figure 5 as determined at the floor of the front and rear cab. It will be noted that the lateral accelerations are usually higher at the rear end, and it should be mentioned that the oscillations of the

body about the vertical axis need not necessarily be true nosing, i.e., rotation about the axis through the centre of gravity. In some cases the body oscillates about a point ahead of it. It will be noted that the accelerations can be separated into two

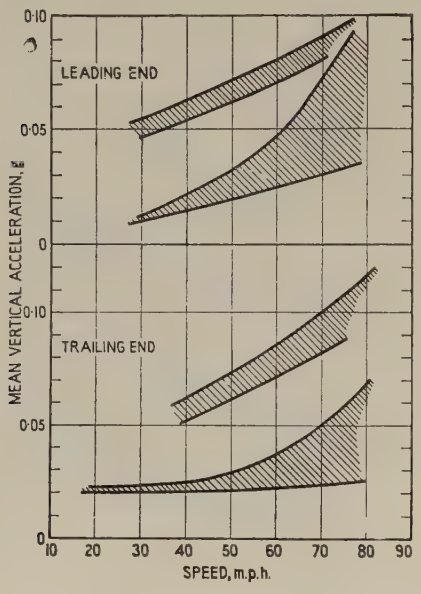


Fig. 6. — Mean values of vertical accelerations measured in the cabs of a number of bogie locomotives.

bands, the lower applying to locomotives with which relatively low frequency oscillations were recorded only, while the higher band relates to locomotives exhibiting both low (0·5 to 3 cycles/sec.) and higher (3 to 10 cycles/sec.) frequency oscillations.

Vertical accelerations.

Representative values of mean vertical accelerations are plotted in figure 6. As in the case of lateral accelerations, it is possible to group the results into two bands, although here the distinction is not quite so pronounced. An analysis based on frequencies of 1 to 5 cycles per sec. only will here obviously give an unduly favourable picture as far as the ride index is concerned, and full account must be taken of the higher frequency range. This point needs stressing in view of the frequently expressed notion that oscillations in excess of 5 cycles per sec. or so do not matter and should be filtered as far as recording is concerned. It is suggested that it should be more correct to filter in two stages and separately record oscillations of up to 5 cycles per sec., i.e., oscillations mainly linked with the action of the suspension and then again the oscillations of higher frequencies due to body vibrations as well as vibrations emanating from engines, auxiliary equipment, etc.

In spite of their significance, the magnitudes of acceleration should not be used as a sole yardstick to judge vehicle behaviour. As indicated by the equations for the ride values, these depend on acceleration as well as upon frequency, and the results of record evaluations in these terms are plotted in figures 7 and 8. As far as vertical oscillations are concerned, the

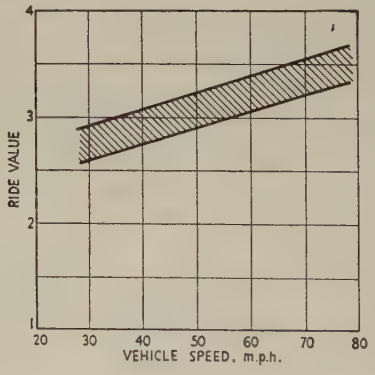


Fig. 7. — Ride index values in the lateral plane as recorded in cabs of modern bogie locomotives.

locomotives show somewhat similar characteristics which, in terms of coach standards, suggest poor riding at speeds in excess of about 70 m.p.h. The riding qualities of the locomotives considered here are entirely satisfactory, however, but in the case of coaches lower values should obviously be aimed at.

Slower speeds.

Because most vehicles run satisfactorily at speeds below 50 to 60 m.p.h. it is seldom necessary to record oscillations below these speeds, unless called for by special considerations. The desirable ride value limits for

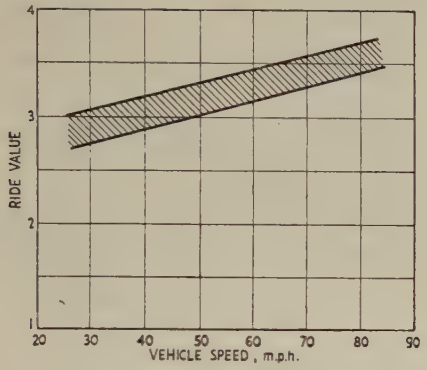


Fig. 8. — Ride index values in the vertical plane as recorded in cabs of modern bogie locomotives.

locomotives might well be increased up to 3·5 to 3·75. With locomotives it is important to ensure good riding qualities at both ends, at the front end for the sake of the crew and at the rear for the sake of the adjoining coach.

Extensive testing for resonance.

To obtain truly representative results it will not do to run vehicles over a given stretch of line at a number of arbitrarily selected speeds. Such tests have their value as a comparison between one vehicle and another, but even so the speeds should be chosen with more regard to previously calculated or experimentally determined resonance conditions to provide more fundamental information for closer correlation between theory and practice, which is of utmost importance for further vehicle development. To obtain truly representative data permitting a correct assessment of the all-round suitability of a vehicle it will be necessary to carry out extensive sample testing with a number of units of the type concerned over widely varying track conditions running in different parts of the train with a wide range of loads and in different states of repair (9).

As far as passenger comfort is concerned, it must be stressed that it is inadequate to base vehicle evaluation on the ride index only. Noise is a very important factor and can effectively offset much in the way of suspension improvement. It is essential, therefore, that in future vibration and noise intensities should be recorded simultaneously and evaluated in terms of a common ride index embracing both, along the lines implicitly suggested by Postlethwaite (2).

As shown in figure 3, low ride index values can be achieved by keeping down the natural frequency and/or the amplitude of the oscillations. Enough has been said about the ways and means of keeping the frequency low (8), but as far as the amplitudes are concerned a brief mention may be made here of the amplitude ratio R as applied to a simple linear system consisting of a mass, a spring with a linear force-displacement characteristic and a viscous damper the resistance of which is proportional to the displacement velocity, figure 9. This is the ratio of the displacement of the body divided by the displacement originating the oscillation. The value of R will be at its highest at resonance, reducing to unity at a frequency of 1·41 times the natural frequency of the system. Thus with impulses coming at 60 ft. intervals and a natural frequency of the system of 1·5 cycles/sec. the resonance speed will be at $1{\cdot}5 \times 60/1{\cdot}467 = 61{\cdot}3$ m.p.h. Reduced natural frequency will not only reduce the resonance speed but also the acceleration. The magnitude of the acceleration is given as $b = e\,(2\pi f)^2$, where e is the amplitude.

The importance of suitable viscous damping is clearly indicated on figure 9 and attention is drawn to the fact that the presence of dampers is undesirable at speeds in excess of 1·41 of the resonance speed. For a number of reasons substantiated both theoretically and experimentally (8), the value of D = 0·2 to 0·25 should be aimed at where for a single mass system D =

$p/2\sqrt{mc}$ with p (lb. sec./ft.) as the damping resistance, m (lb. sec.^{2}/ft.) the mass, and c (lb./ft.) the spring stiffness. The relevant equations for a two degree of freedom system applied to the suspension of vehicles have been considered previously (10 *a*).

So far as vertical oscillations are concerned, we are faced with bouncing and pitching

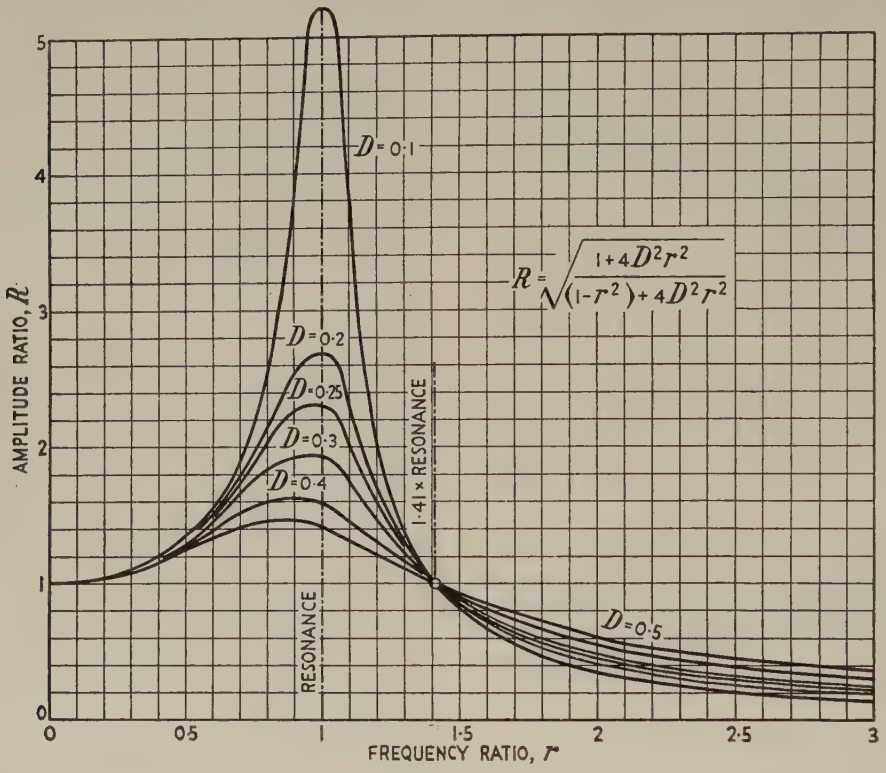


Fig. 9. — The effect of viscous damping on the amplitude ratio of a simple linear system.

Speed (m.p.h.)	30	40	50	60	70	80	
Freq. of Excit. f (*c./s.*) . .	1·467	1·96	2·44	2·934	3·42	3·92	
f/f_p	0·585	0·853	0·975	1·175	1·37	1·57	
Ampl. Ratio R	1·42	2·16	2·3	1·67	1·06	0·76	From figure 9
ex R (in.)	0·085	0·13	0·138	0·1	0·064	0·046	
Acceler. g	0·019	0·051	0·084	0·088	0·077	0·071	$b = e\,\frac{(2\pi f)^2}{386}$
Ride Index	2	2·8	3·2	3·45	3·35	3·35	From figure 3 *a*

Speed (m.p.h.)	30	40	50	60	70	80
f/f_p	0·725	0·967	1·2	1·445	1·68	1·92
Ampl. Ratio R	1·76	2·3	1·6	0·94	0·65	0·48
ex R (in.)	0·105	0·138	0·096	0·0565	0·039	0·024
Acceler. g.	0·023	0·054	0·058	0·05	0·047	0·047
Ride Index	2·1	2·8	2·95	2·92	2·9	2·9

and of these the latter is more important. The natural frequency of a symmetrical vehicle body pitching about the lateral (Y) axis through its centre of gravity is obtained from the formula :

$$f = \frac{a}{6{\cdot}28}\sqrt{\frac{c}{I_y}}$$

where 2 a (ft.) is the distance between bogie centres, c (lb./ft.) the total spring stiffness and I_y (lb. ft. sec.^{2}) the moment of inertia about the Y-axis. Generally the value of I_y is obtained from :

$$I_y = m(xL^2)$$

where L (ft.) is the body length over the buffer beams, whilst $x = 0{\cdot}22$ to $0{\cdot}25$ for diesel and electric locomotives, $0{\cdot}33$ for coaches, and $0{\cdot}28$ for railcars with underfloor engines. If the body pitches about one of the bogies then :

$$I'_y = I_y + 2ma^2$$

Similar considerations apply to the body hunting on the swing links or similar devices, about the vertical (Z) axis through the centre of gravity. In this case it will be sufficiently accurate to assume $I_z = I_y$.

Thus if the magnitude of the excitation amplitudes and the natural frequency and the damping factor of the system are known, it will be possible to determine the magnitude of the ride index values. For example, with a natural frequency of pitching $f_p = 2{\cdot}5$ and an excitation impulse every 30 ft. the ride index values can be determined along the lines shown in the upper table, assuming the amplitude of excitation $e = 0{\cdot}06$ in. at the bottom bolster plank and a damping factor of 0·25 (11.)

The data shown relate to heavily damped primary springs and bolster springs with a static deflection of 2·64 in. Increasing the latter value to 4 in. will reduce the frequency of pitching to 2·03 cycles/sec. Proceeding as before, the revised figures are shown in the lower table.

The advantage thus obtained amounts to an index reduction of about 0·5, in this case improving the quality of the ride from just satisfactory to satisfactory. It is of interest to compare these results with experimental evaluation, figure 10.

Similar considerations apply to the ride in the lateral plane as far as body nosing, *i.e.*, rotation about the vertical (Z) axis through the centre of gravity and displacement along the lateral (Y) axis through the centre of gravity is concerned.

The lateral oscillations of the vehicle body considered here are assumed to be caused by the sinusoidal motion of the wheels. The actual frequencies of these oscillations are plotted in figure 4, and also in figure 5 of reference (8). The bogies usually follow each other along the track, the rear one following the front bogie with a phase angle $\varnothing$. Figure 11. The wavelength L (ft.) of the sinusoidal motion L corresponds to one complete cycle (2π) while the distance a (ft.) between the bogie centres corresponds to $\varnothing$ (12) and since :

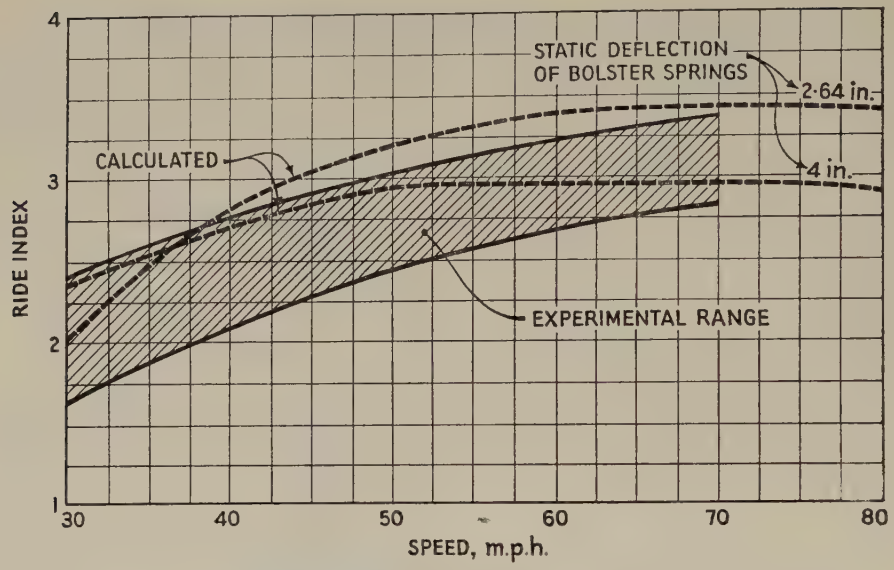


Fig. 10. — Vertical ride index values for a railcar trailer. The importance of ensuring adequate bolster spring deflection is apparent.

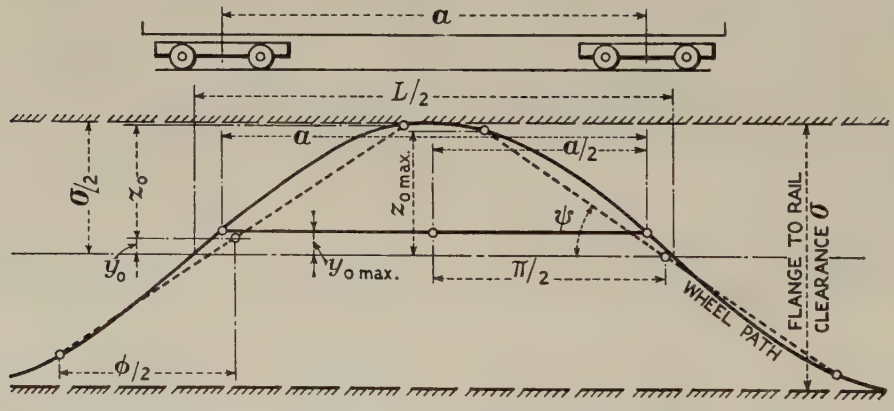


Fig. 11. — The nosing motion as a combination of rotation and lateral displacement. The wavelength L (ft.) corresponds to one complete cycle (2π).

$L/a = 2\pi/\varnothing$, it follows that $L = 2\pi a/\varnothing = v/f$ and $\varnothing = 2\pi af/v$, where v (ft./sec.) is the vehicle speed. The body rotates about the vertical (Z) axis through the centre of gravity, the relevant angle being :

$$\psi = z/(a/2), \text{ where } z = (\sigma/a) \sin \varnothing/2$$

where σ is the clearance between the wheel flanges and the rails, $\sigma/2$ being equivalent to the maximum lateral displacement to each side of the centre line of the track. Consequently :

$$\psi = (\sigma/a) \sin (\pi/2) (2af/v).$$

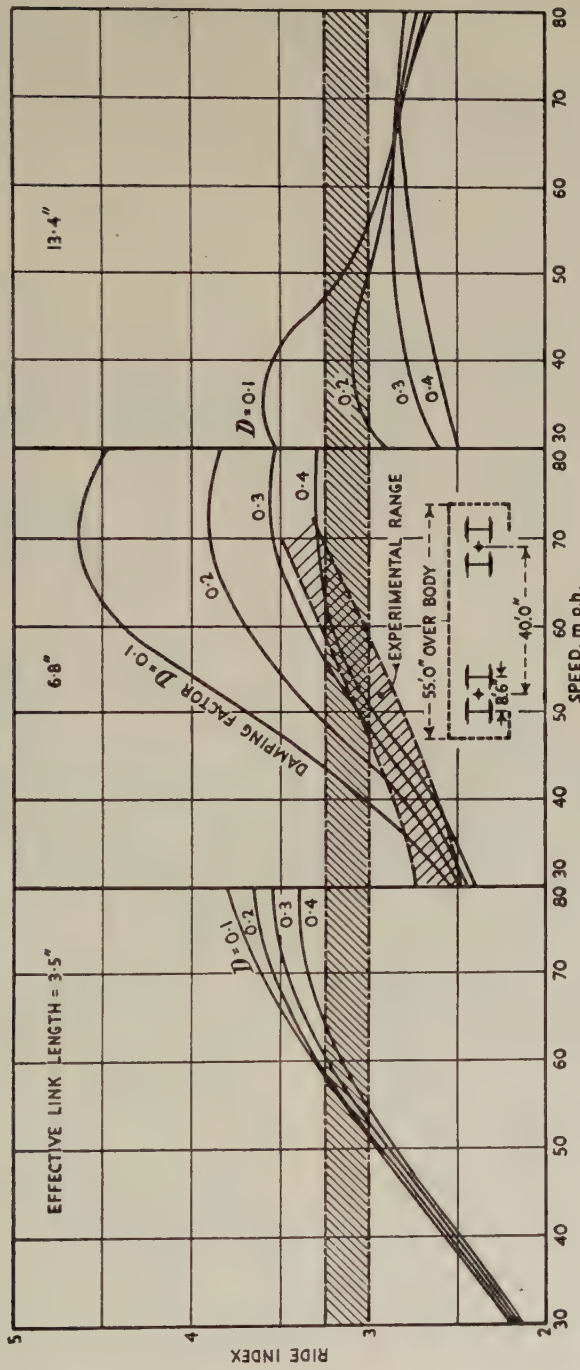


Fig. 12 *a*. — The effect of swing link length and damping factor on lateral ride index when running on « poor » track ($\sigma = \pm 0{\cdot}25$ in.).
The bottom curve on left is plotted from tabulated data on page 693.

The amplitude of excitation of body rotation is :

$z_o = \pm\psi(a/2) = \pm(\sigma/2) \sin (\pi/2) (2af/v)$. Generally both rotation about the vertical (Z) axis and displacement about the lateral (Y) axis are present simultaneously to induce nosing, and the amplitudes concerned are added to :

$$x_t = z'_o + y'_o$$

where $z'_o = \pm (\sigma/2) \sin^2(\pi/2) (2af/v)$,

and $y'_o = \pm (\sigma/2) \sin^2(\pi/2) [(2af/v) - \pi/2]$

To approximate the most unfavourable conditions, it will be permissible to neglect the phasing and determine z'_o only, while $y'_o = (\sigma/2) - z'_o$.

To determine the magnitude of lateral displacements, accelerations and ride index, it will be necessary to know the natural frequency of the lateral oscillations :

$$f_l = (1/2\pi)\sqrt{c/m} \text{ (cycles/sec.)}$$

as well as the natural frequency of the body hunting :

$$f_h = (a/2\pi)\sqrt{c/I_z},$$

where c (lb./ft.) is the total lateral centring force imposed on the vehicle body by the swing links, etc., m (lb. sec.^{2}/ft.) is the body mass, and I_z (lb. ft. sec.^{2}) its inertia about the vertical axis, $I_z = mr^2$, where for diesel and electric locomotives $r = 0{\cdot}22$ to $0{\cdot}25$ L, while for coaches $r = 0{\cdot}3$ to $0{\cdot}33$ L. Once the values of f_l and f_h as well as the excitation frequency f due to the wheels are known, the ratios f/f_l f/f_h provide the values of the Amplitude Ratio R (figure 9) and this multiplied with x_t gives the magnitude of the body displacement d and the acceleration $b = d(2\pi f)^2$. The latter, together with f permits the determination of the ride index values from the graphs, figure 3 *b*.

These considerations are, in the following, applied to a vehicle with the distance between bogie centres $2a = 40$ ft., the lateral clearance between flanges and rails being limited to $\sigma/2 = \pm 0{\cdot}25$ in., while the natural frequency of the body nosing on the swing links was calculated as $f_h = 1{\cdot}87$ c/s as compared with $f_l = 1{\cdot}67$ c/s for the purely lateral oscillations. The frequency of excitation due to the sinusoidal motion of the wheels was estimated along the lines shown in figure 4. The shaded band is the result of experimental determinations. The value of z'_0 is obtained as :

$$z'_0 = \pm 0{\cdot}25 \sin^2 \left(\frac{\pi}{2} \times \frac{f}{v} \times 2 \times 40\right)$$

$$= \pm 0{\cdot}25 \sin^2 \frac{\pi 40 f}{1{\cdot}467 \text{ V (m.p.h.)}}$$

$$= \pm 0{\cdot}25 \sin^2 85{\cdot}5 f/\text{V}$$

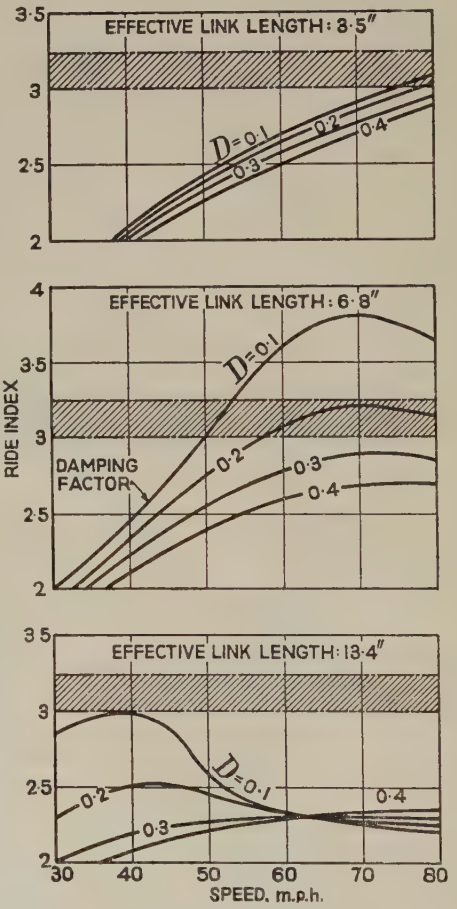


Fig. 12 *b*. — The effect of swing link length and damping factor on lateral ride index when running on « good » track ($\sigma = \pm 0{\cdot}125$ in.).

Speed (m.p.h.)	30	40	50	60	70	80	
Freq. of excit. f (*c./s.*) . .	0·9	1·02	1·17	1·29	1·4	1·47	Figure 4
Ampl. Ratio R	0·48	0·545	0·625	0·69	0·748	0·785	For $f_h = 1{\cdot}87$
z'_o (in.)	0·134	0·204	0·228	0·241	0·243	0·25	
$z = R \times z'_o$ (in.)	0·164	0·265	0·323	0·366	0·382	0·4	
Ampl. Ratio R	0·538	0·61	0·7	0·773	0·84	0·88	For $f_l = 1{\cdot}67$
$y'_o = \sigma/2 - z'_o$ (in.) . .	0·116	0·046	0·022	0·009	0·007	0	
$y'_o = R \times y'_o$ (in.) . . .	0·15	0·065	0·033	0·014	0·011	0	
$y'_o + z'_o$ (in.)	0·314	0·33	0·356	0·38	0·393	0.4	
Acceler (g)	0·026	0·035	0·05	0·065	0·079	0·084	$b = \dfrac{(y_o + z_o)\,(2\pi f)^2}{386}$
Ride Index	2·15	2·52	2·9	3·15	3·35	3·4	From figure 3 *b*

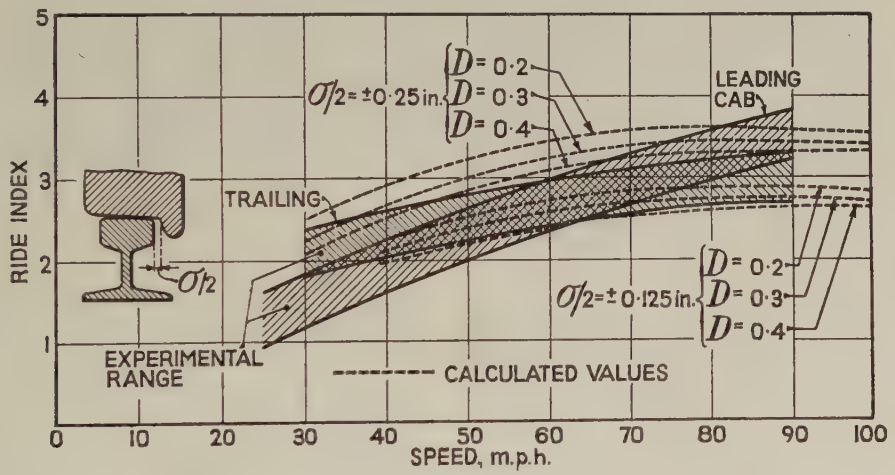


Fig. 13. — Calculated and experimentally determined lateral ride index values for a Co-Co locomotive.

The resultant tabulated values are given above for a damping factor of 0·4 and a swing link length of 3·5 in.

The results are plotted in figure 12 *a* together with ride index value obtained for longer swing links and a number of damping factors. The experimental values recorded with a vehicle of this type are entered as well, suggesting that reasonable correlation between simplified theory and practice is possible. These values relate to indifferent track, experience suggesting that

the lateral accelerations of the vehicle body are practically halved on well-maintained track. The resultant index values are plotted in figure 12 *b*. It is of particular interest to note that damping is of relatively little importance with short swing links, a fact substantiated by experience with some recent bogie designs with which carefully adjusted friction damping can be quite adequate to ensure good riding.

Good correlation between theory and practice is also suggested by the data plotted in figure 13 relating to a Co-Co locomotive.

Generally to ensure good riding in the lateral plane it will pay to keep, for a given body length L, the distance 2 *a* between the bogie centres as large as possible and the body overhang at each to less than 0·15L. The ratio of distance between bogie centres and I_z should be a maximum. To achieve this, heavy masses such as power plant should be at or near the vehicle centre so keeping I_z small.

The above considerations show the utility of this particular method of ride evaluation in readily providing data which permits comparison of vehicle performance in simple and unambiguous terms. In addition, it is possible to calculate the ride index values of vehicles in course of design, this facilitating a better appreciation of the influence of the design variables. Admittedly this simple method does not take in account all the possible combinations and permutations of extraneous influence encountered by vehicles in service. Simplifying assumptions can be made here at this stage, but even so the data obtained can be of considerable assistance to designers.

The ride index values, figure 3, are also of assistance when considering the performance of vibration dampers. For example, if at a frequency of 2 cycles per sec. the vertical index value should not exceed 3·2, then from figure 3 a the acceleration should not exceed 0·065 g or 25 in. per sec.^{2}, this value applying for the bolster springs of a vehicle with heavily damped primary springs. The amplitude of the oscillations should thus not exceed 0·155 in. per sec. which corresponds to a velocity of 10 ft. per min. The spring stiffness *c* (lb./ft.) permits the determination of the damping resistance *p* (lb. sec./ft.) and thus of the damper characteristic. The value of *p* is obtained from the relation :

$$p = 2D\sqrt{mc}$$

where D is the required damping factor.

Recent vehicle development has led to the introduction of railcars and locomotives with unsymmetrical bodyweight distribution resulting in the use of bogies of differing design at each end. Representative designs of this type are the power cars of the German TEE trains and the power cars of British Railways de luxe trains, the power cars of B.R. Southern Region diesel-electric trains, the London Midland Region 1 200 h.p. Type « 2 » Class D5700 Co-Bo diesel-electric locomotives and the electric Co-Bo 50-cycle locomotives of the Hungarian State Railways.

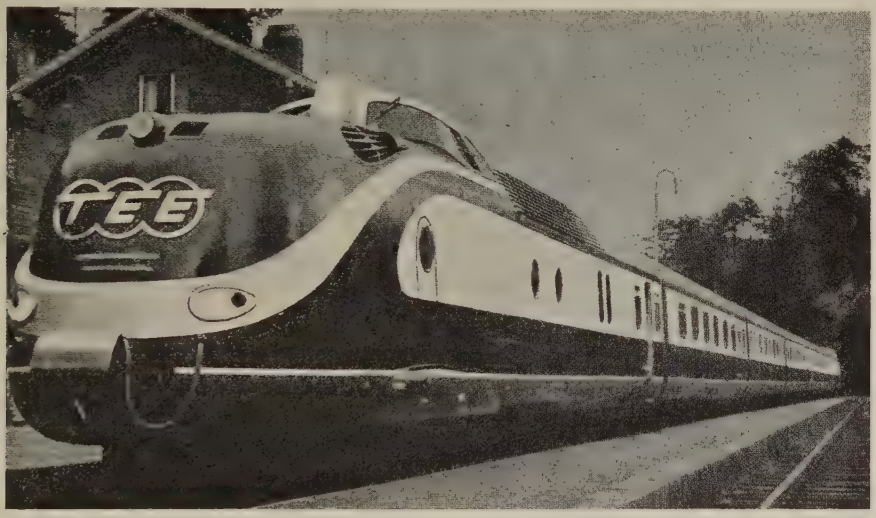
With symmetrical vehicles having an even weight distribution and using bogies of identical design incorporating springs of equal stiffness at each end, bouncing oscillations will not excite pitching and vice-versa. Here the body has two degrees of freedom in the vertical plane, one in translation about the lateral (Y) axis through the centre of gravity, and the other in rotation, but since generally there is no coupling action between these modes, they will not affect each other. With *a* (ft.) and *b* (ft.) being the distance from the front and rear bogie centre to the centre of gravity of the body and *r* (ft.) as the radius of gyration, a special case will be represented by the relationship $ab = r^2$. In this case the springs will not affect each other since each is a centre of oscillation for the other. Similar considerations apply to the lateral oscillations of the body on the swing links or due to the lateral elasticity of helical bolster springs (8, 13).

Determination of natural frequencies.

When it comes to oscillation of unsymmetrical systems due consideration must be given to the presence of a coupling effect between inertia and spring forces. As

shown in figure 13 the natural frequency ω_b (radians per sec.) of purely bouncing oscillations can be readily determined as long as the spring stiffness c_t and the body mass are known and provided the body is ideally, without friction, restrained to move only up and down. Similarly, if the body is restrained to rotate about the lateral (Y) axis through the centre of gravity, it is possible to determine the natural frequency of pitching ω_p as also shown in figure 14. However, as far as bouncing is concerned, the vehicle body will tend to pursue a purely translatory motion only as long as the resultant P_t of the spring forces P_a and P_b will pass through the centre of gravity, i.e. as long as $a = b$ and $P_a = P_b$ or $c_a \times a = c_b \times b$, i.e. $c_a/c_b = b/a$, where c (lb./ft.) is the spring stiffness due to the springs at one end of the vehicle. If this is not the case then the spring coupling moment M_{cv} due to the action of the resultant spring force P_t on the centre of gravity of the body via the arm k_{cv} will tend to rotate the body, thus exciting pitching oscillations at the centre of gravity. Reference is made to a « positive coupling » if P_t is applied ahead of the centre of gravity, while the coupling becomes negative if $c_a a < c_b$ (14).

If the body is restrained to oscillate only about the lateral (Y) axis through the centre of gravity, figure 14, then the axis bearings will be required to deal with the instantaneous forces due to the spring deflection. Here the forces due to the two sets of springs will oppose each other since one is compressed and the other expanded, the resultant force P_c being the difference of the absolute values of these spring forces. The value of P_c is given in figure 4 and it becomes zero for $c_a/c_b = b/a$, i.e. the spring coupling force will disappear under the same circumstance as would the spring coupling moment M_{cv} of the bouncing oscillations. Unlike K_{cv} the spring coupling factor K_{cp} applicable to pitching does not permit a simple geometrical interpretation. It is a magnitude which multiplied with a moment will provide a force. If now the body is free to move without being restrained at the centre of gravity, then the



A good example of unsymmetrical bogie vehicles is the motor car of the diesel-hydraulic TEE train of the German Federal Railways.

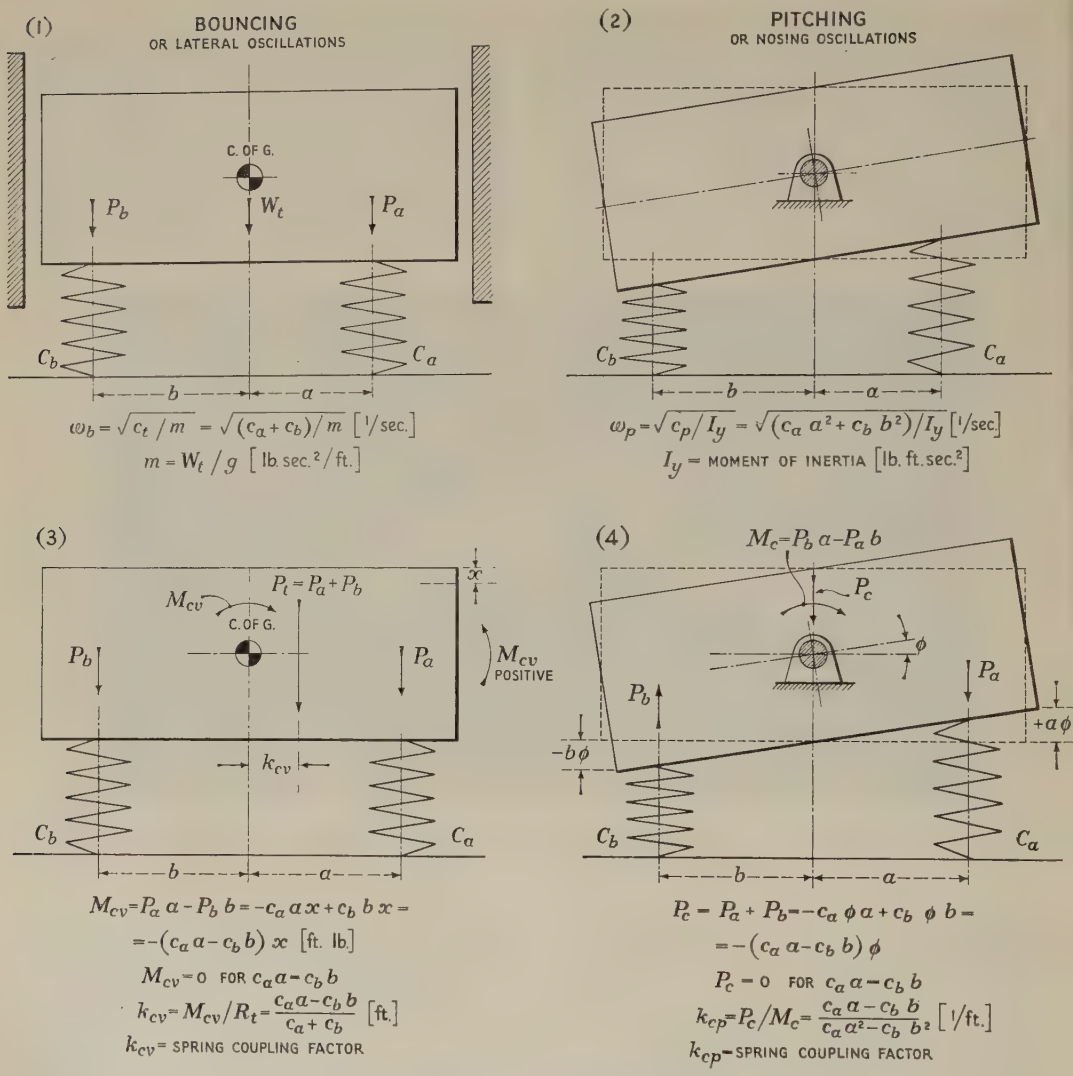


Fig. 14. — The pattern of oscillation and the determination of natural frequencies of unsymmetrical systems.

coupling force P_c will result in bouncing oscillations of the centre of gravity being excited as the result of pitching. Similar considerations apply to the coupling action of dampers.

Simultaneous oscillations.

The above considerations indicate that the vehicle body will bounce and pitch simultaneously, the motion being composed of oscillations about an axis located between the bogie centres and one outside these. The oscillations at a lower natural frequency will resemble bouncing, while those at a higher frequency will be more akin to pitching. The lower (ω_I) and higher (ω_{II}) frequencies of these oscillations are derived (15) from the following equation :

$$\omega_{I,\,II} = \sqrt{\left(\frac{\omega_b^2 + \omega_p^2}{2}\right) \pm \sqrt{\left(\frac{\omega_b^2 - \omega_p^2}{2}\right)^2 + \frac{(c_a a - c_b b)^2}{mI}}} \quad \text{[rad./sec.]}$$

where m [lb. sec.^{2}/ft.] is the mass and I [lb. ft. sec.^{2}] the moment of inertia of the vehicle body.

It might be mentioned here that for vehicle bodies generally the moment of inertia about the vertical (Z) and lateral (Y) axis through the centre of gravity are approximately equal, being given by :

$$I_z = I_y = mr^2 \text{ [lb. ft. sec.}^2\text{]}.$$

If the body centre of gravity is located at some distance e [ft.] from the centre of the vehicle, then in accordance with the parallel-axis theorem the moment of inertia of the body with respect to this axis will be :

$$I_{z1} = I_{y1} = mr^2 + me^2 = m(r^2 + e^2) \quad \text{[lb. ft. sec.}^2\text{]}.$$

If the bogies have primary suspension only, then the sprung mass of the bogies is virtually attached to the body as far as vertical oscillations are concerned, so that the total moment of inertia about the Y-axis will be :

$$I_y = m(r^2 + e^2) + I_{fb} + m_{fb}a_1^2 + I_{rb} + m_{rb}b_1^2,$$

where I_{fb} is the moment of inertia of the front bogie about its centre of gravity and a_1 the distance from the centre of gravity of the bogie to that of the vehicle, the index f and r referring to the front and rear bogie, respectively.

The moment of inertia of the sprung portion of the bogies about the relevant centre of gravity less the sprung mass of the axle-hung motors is approximately given by :

$$I_{yb} = m_b l^2/12 \quad \text{[ft. lb. sec.}^2\text{]}$$

where l [ft.] is the frame length.

The centres of rotation of the two modes of oscillations can be determined as shown in figure 15 (16). Here it is of interest that the product of the translation co-ordinate (m) and the rotation co-ordinate (n) is equal to the square of the radius of gyration.

Application of formulae.

The application of the above considerations may be illustrated for the case of a heavy power car of a 2 200-b.h.p. seven-car 226-ton diesel-hydraulic German Federal Railways Trans-Europ Express train (17), illustrated on page 695.

The approximate plan layout of this is shown in figure 16. The 63 ft. long vehicle body weighs 36·5 tons of which 24 tons are carried by the driving (front) bogie. With a distance of 41 ft. 6 in. between bogie centres the centre of gravity will be 14 ft. 3 in. to the rear of the power bogie. The 1 100-h.p. engine weighs about 3 tons. It is about 5 ft. wide and some 6 ft. 3 in. long, and its centre is about 20 ft. ahead of the centre of gravity of the vehicle. Consequently, its moment of inertia relative to the centre of gravity of the vehicle body is :

$$\begin{aligned} I_{ze} &= m\,(b^2 + h^2)/12 + mr_e^2; \\ &= (3 \times 2\,240/32{\cdot}2)\ (6{\cdot}3^2 + 5^2)/12 + 208 \times 20^2; \\ &= 84\,500 \quad \text{[ft. lb. sec.}^2\text{]}. \end{aligned}$$

The hydraulic transmission weighs about 3·3 tons and its centre is about 12·6 ft. ahead of the centre of gravity of the vehicle body. It is about 3·8 ft. wide and 5 ft. long. Proceeding as above :

$$I_{zt} = 37\,000 \quad \text{[ft. lb. sec.}^2\text{]}.$$

The vehicle body (less engine and transmission) carries auxiliary power plant, fuel tanks, the engine cooling equipment, brake equipment, batteries, heating equipment, and so on. Because of this its moment of inertia will be considered as being equivalent to that of a diesel locomotive of similar layout, i.e. :

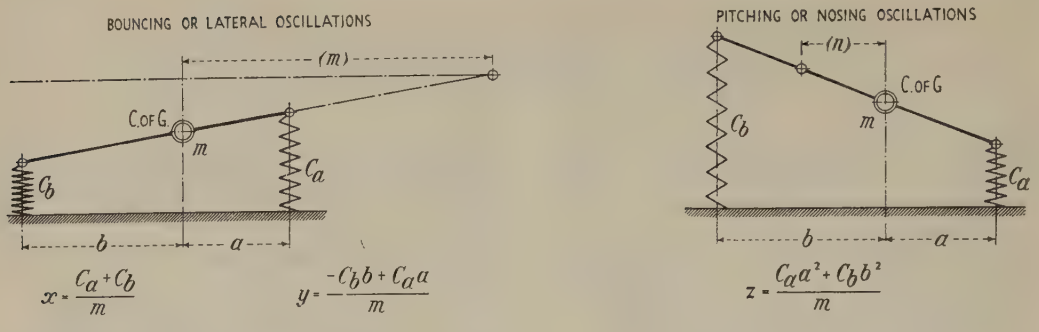

BOUNCING OR LATERAL OSCILLATIONS
(m)
C.OF G.
m
C_b
C_a
b
a
PITCHING OR NOSING OSCILLATIONS
(n)
C.OF G.
m
C_b
C_a
b
a
$x = \frac{C_a + C_b}{m}$
$y = -\frac{-C_b b + C_a a}{m}$
$z = \frac{C_a a^2 + C_b b^2}{m}$
$(m)(n) = \frac{-y}{\frac{1}{2}\left(\frac{z}{r^2} - x\right) + \sqrt{\frac{1}{4}\left(\frac{z}{r^2} - x\right)^2 + \frac{y^2}{r^2}}} \times \frac{+y}{\frac{1}{2}\left(\frac{z}{r^2} - x\right) - \sqrt{\frac{1}{4}\left(\frac{z}{r^2} - x\right)^2 + \frac{y^2}{r^2}}} = \frac{-y^2}{\frac{1}{2}\left(\frac{z}{r^2} - x\right)^2 - \frac{1}{4}\left(\frac{z}{r^2} - x\right)^2 - \frac{y^2}{r^2}} = r^2$
r = RADIUS OF GYRATION
FOR $C_b \times b = C_a \times a$: $y = 0$ AND $(n) = 0$ AND $(m) = \infty$ i.e. UNCOUPLED PITCHING AND BOUNCING OR UNCOUPLED NOSING AND LATERA
OSCILLATIONS

Fig. 15. — The determination of the centres of rotation of unsymmetrical systems.

$$I_{zb} = mr^2 = m\,(0{\cdot}22L)^2;$$
$$= (36{\cdot}5 - 6{\cdot}3) \times (2\,240/32{\cdot}2) \times (0{\cdot}22 \times 63)^2;$$
$$= 405\,000 \quad \text{[ft. lb. sec.}^2\text{]}.$$

This value will be further increased due to the fact that the centre of gravity of the body assembly (less engine and transmission) is some 41·5/2 — 14·25 = 6·5 ft. away from the centre of gravity of the complete body, the resultant value being :

$$I_{zb} = me^2 = 2\,100 \times 6{\cdot}5^2 = 89\,000 \quad \text{[ft. lb. sec.}^2\text{]}.$$

The total moment of inertia of the vehicle body is the sum of the above values :

$$I_{zt} = 605\,500 \quad \text{[ft. lb. sec.}^2\text{]}.$$

Lateral stiffness.

The bogies are provided with vertical swing links, the length being 13 3/4 in. and 17 3/4 in. for the power and trailing bogie, respectively. Consequently the lateral stiffness of the bolster suspension is :

$$c_1 = 24 \times 2\,240 \times 12/13{\cdot}75 = 47\,000 \quad \text{[lb. per ft.]}$$

for the power bogie, while for the trailing bogie $c_1 = 19\,000$ [lb. per ft.]. The mass of the complete vehicle body is :

$$m = 36{\cdot}5 \times 2\,240/32{\cdot}2 = 2\,540 \quad \text{[lb. sec.}^2\text{/ft.]}$$

so that in accordance with the equation of figure 1 :

$$\omega_b = \sqrt{(47\,000 + 19\,000)/2\,540} = \sqrt{26} = 5{\cdot}1 \text{ [radians/sec.]}$$

whilst $f_b = \omega/2\pi = 0{\cdot}81$ (cycles/sec.). Similarly, in accordance with figure 2.

$$\omega_p = \sqrt{\frac{47\,000 \times 14{\cdot}25^2 + 19\,000 \times 27{\cdot}25^2}{605\,500}}$$
$$= \sqrt{15{\cdot}8 + 23{\cdot}5}$$
$$= \sqrt{39{\cdot}3} = 6{\cdot}27 \text{ [radians/sec.]}$$

and $f_p = 1$ [cycle/sec.].

Thus the frequency of purely lateral oscillations is about 0·8 cycles per sec. as compared with 1 cycle/sec. for the oscillations of the body rotating about the vertical (Z) axis through the centre of gravity. The frequency of the coupled oscillations ω_I and ω_{II} can now be determined from :

$$\omega_{I,\,II} = \sqrt{\left(\frac{26+39{\cdot}4}{2}\right) \pm \sqrt{\left(\frac{26-39{\cdot}4}{2}\right)^2 + \frac{(47\,000\times 14{\cdot}25-19\,000\times 27{\cdot}25)^2}{2\,540\times 605\,500}}}$$

$\omega_I = 5$ [radians/sec.], $\omega_{II} = 6{\cdot}37$.

The two coupled frequencies are :

$f_I = 0{\cdot}8$ [cycles/sec.] and $f_{II} = 1{\cdot}01$.

The vehicle speeds at which these frequencies will be in resonance with the sinusoidal oscillations of the wheels down the track can be obtained from the curves of figure 5, reference (8). Here for 3 ft. diameter wheels the frequency of 0·8 cycles per sec. corresponds to a road speed of about 35 m.p.h. as compared with 40 m.p.h. for 1 cycle per sec.

about 4 ft. to the rear of the centre of gravity and about 1 ft. ahead of the physical centre of the vehicle body. The semi-lateral oscillations will take place about a point some 58 ft. to the rear of the centre of gravity or some 31 ft. behind the rear bogie centre. The pattern of such coupled oscillations can be made clear with the aid of a simple model (18).

It is further of interest to determine the ride index values likely to be obtained in the lateral plane. The relevant calculations were carried out for a wheel flange-to-rail clear-

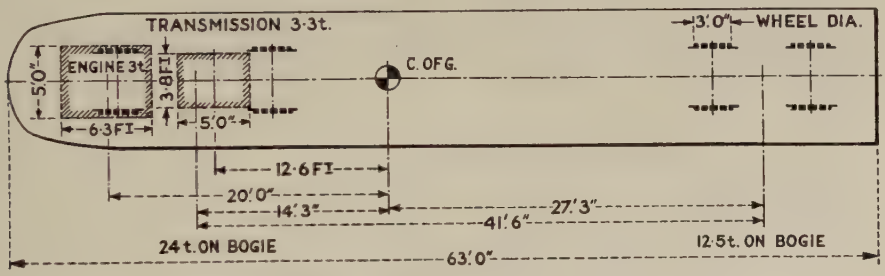


Fig. 16. — Weights and dimensions of a 1 100-h.p. power car.

The position of the centres of oscillation can be determined along the lines indicated in figure 15. Here :

$x = \omega_b^2 = 26$, $y = (47\,000\times 14{\cdot}25-19\,000\times 27{\cdot}25)/2\,540 = 57{\cdot}8$;

$z = (47\,000\times 14{\cdot}25^2 + 19\,000\times 27{\cdot}25^2)/2\,540 = 9\,330$.

The radius of gyration of the vehicle body with respect to centre of gravity is : $r^2 = 605\,000/2\,540 = 238$ ft.^{2} and $r = 15{\cdot}4$ ft., so that the ratio $r/L = 0{\cdot}244$. Consequently $z/r^2 = 39{\cdot}2$, whilst $y^2/r^2 = 14$. With these values :

$$(m)\,(n) = \frac{-57{\cdot}8}{{}^1/_2\,(39{\cdot}2-26)+\sqrt{{}^1/_4\;13{\cdot}2^2+14}} \times \frac{57{\cdot}8}{6{\cdot}6-7{\cdot}55} = -4{\cdot}1\times -57{\cdot}8$$

$$= r^2 = 237\ [\text{ft.}^2]$$

The centre of nosing oscillations will be

ance of 1/4 in. to each side, the frequency of excitation being in accordance with the data of figure 5, reference (8). Due account must be taken of the fact that body nosing consists of simultaneous displacement along the lateral (Y) axis and rotation about the vertical (Z) axis. With due regard for the resultant pattern of wheel motion and body oscillation and with particular reference to the relative transmissibility as affecting the magnitude of body displacement and with it the resultant lateral acceleration, it is possible to determine the ride index as a function of excitation frequency, i.e. vehicle speed (8). The resultant data is plotted in figure 17 for a lateral damping factor of $D = 0{\cdot}3$ and 0·4 which should be generally aimed to achieve satisfactory results (1).

It will be noted that at speeds in excess of about 60 m.p.h. the ride index is of the order of 2·7 to 2·75 which in itself is satisfactory though not quite as good as should

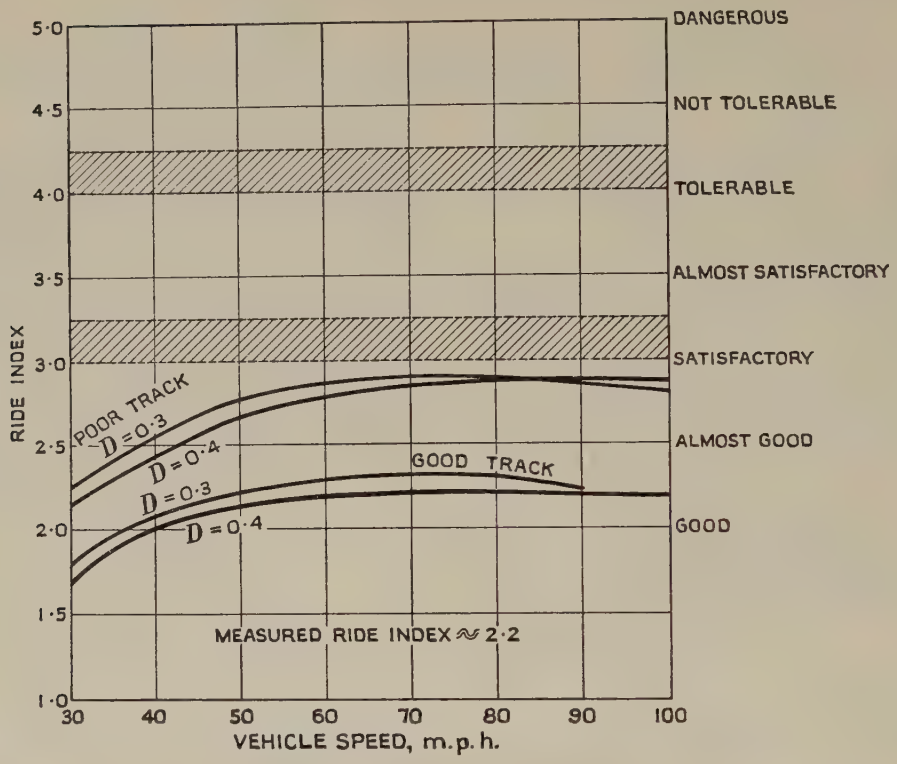


Fig. 17. — Ride Index data of the 1 100-h.p. power car.

An unsymmetrical bogie vehicle on British Railways, the Type « 2 » Co-Bo diesel-electric locomotive built by Metropolitan-Vickers-Beyer Peacock Limited.

be aimed at with up-to-date vehicles. These values were obtained on the basis of a somewhat indifferent track inducing a free lateral displacement of ± 1/4 in. between wheel flanges and rails. With good track the relevant lateral accelerations can be reduced by as much as half of the previously obtained values, and the ride index values would be reduced to about 2·2 to 2·3. It might be of interest to mention that with the latest TEE trains the measured ride index value (17) is of the order of 2·2.

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Electronic automation in public transport undertakings.

At the XXXIIIrd International Congress, held in Paris in June 1959, of the International Union of Public Transport, a report under the above title was presented by Mr. MROSS, Director of the Hamburger Hochbahn. For the benefit of our readers, and with the agreement of the author, we have deemed it useful to summarize the principal subjects covered by the report.

After a brief review of the first realisations of electronic computers, and of the principal conditions for their utilisation, a list is presented of the possible applications of such machines in various spheres of transport undertakings.

In the field of accountancy, electronic data processing machines are used with advantage for stores administration, for the calculation of wages and salaries, for assessing the productivity and cost price of maintenance and repair works carried out in the workshops, for operating statistics (e.g. vehicle kilometres, seat kilometres, etc., per day, per week and per month, or per route or section of route), as well as for auditing the takings of bus and tram conductors. The last-named data are obtained with the aid of a punched tape issued by the ticket printing machines carried by the conductors, and yield the following results :

(*a*) individual accounts of the fares collected, showing details of any differences between the final result of the account, and the amount of money paid in;

(*b*) conductors' accounts;

(*c*) statistics of passengers conveyed and fares received, classified by categories of tickets and by routes;

(*d*) accounts of the daily receipts of each garage, depot or cash office.

Transport undertakings which use electronic data processing machines for all the applications listed above have already made considerable progress on the way towards automation of their accounting work and are able to deal in a similar way with stores, supplies, adjustments in the value of assets, depreciation as well as other accountancy items.

Turning to the use of electronic data processing machines in the field of transport operation, it is first of all possible to envisage the calculation of timetables and duty rosters and the preparation of traffic surveys.

Timetables.

Working in collaboration with mathematicians of a company producing office machinery, the Baltimore Transit Company has worked out an electronic programme permitting the compilation of timetables. With the aid of this programme, it is possible to obtain the timetable for one route within 20 min — a job which might take a trained schedule compiler several weeks. The first timetables produced by electronic methods were introduced on 14 bus routes in January 1957.

The programme required for the compilation of timetables by electronic methods is based on the electronic operations which ensure that the service offered on the different sections of route, carrying different volumes of traffic, is flexibly adapted to the traffic demand. By taking as a basic element a regular headway of 20 or 30 min, one thus obtains the numbers of additional vehicles which must be worked during these intervals if the number of seats offered shall not exceed the traffic demand. Electronic units are

able to carry out this work more efficiently than any timetable office, however well conducted, which must use conventional manual calculating methods. In fact, the calculating and storage units of the electronic data processing machines are able to calculate at lightning speed, to select and combine in many different ways, and to arrive at reliable decisions.

In order to carry out the operations required from it, the electronic data processing unit must be provided with the following information :

(1) statistical data concerning the traffic demand :

(*a*) on each day of the week on which the demand differs;

(*b*) on each section of route on which the traffic volume differs;

(*c*) during each 20 or 30 min period of the day;

(2) the capacity of the vehicles available for service, and the accommodation offered at different times of the day; during peak periods, 60 passengers per vehicle are allowed, instead of 45 at other times;

(3) the running times on each section of route at different times of the day, depending on the degree of traffic congestion.

On the strength of these data, the electronic data processing machine is able to evaluate the traffic demand on the route, and to calculate the service accordingly.

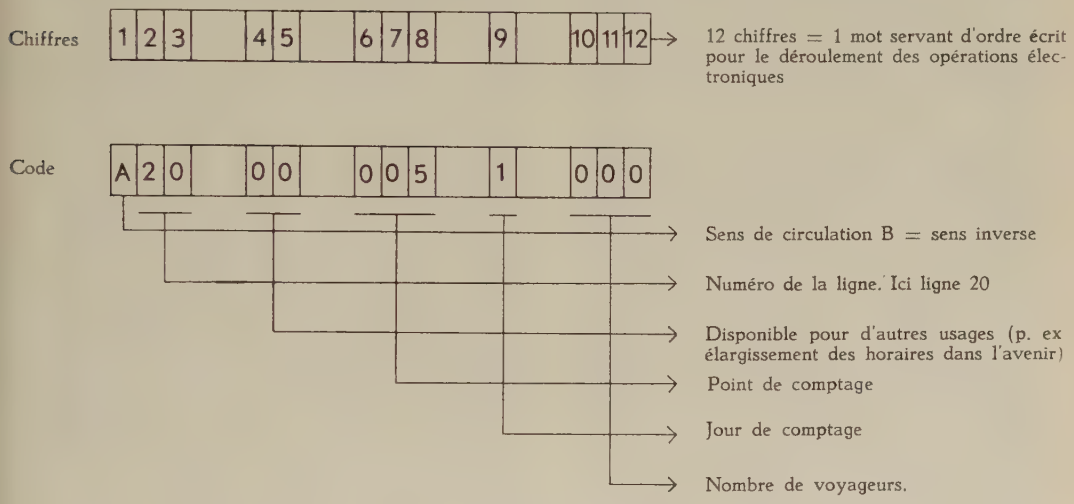

Chiffres
1 2 3 4 5 6 7 8 9 10 11 12
12 chiffres = 1 mot servant d'ordre écrit pour le déroulement des opérations électroniques
Code
A 2 0 0 0 0 0 5 1 0 0 0
Sens de circulation B = sens inverse
Numéro de la ligne. Ici ligne 20
Disponible pour d'autres usages (p. ex élargissement des horaires dans l'avenir)
Point de comptage
Jour de comptage
Nombre de voyageurs.

Fig. 1.

Explanation of French wording :

Chiffres = figures. — 12 chiffres = 1 mot... électroniques = 12 figures : 1 word used as a written order for the development of the electronic operations. — Sens de circulation B = sens inverse = direction of movement B = reverse direction. — N° de la ligne. Ici ligne 20 = No. of the line. Here line 20. — Disponible... dans l'avenir) = Available for other uses (for instance development of the timetables in the future). — Point de comptage = numbering point. — Jour de comptage = numbering day. — Nombre de voyageurs = number of passengers.

The data sheet must be prepared in such a way that it can be used for feeding the data into the electronic machine. The layout and contents of the data sheet used by the Baltimore Transit Company are reproduced above (fig. 1).

These recorded data are supplemented by the following details :

(*a*) vehicle numbers;

(*b*) working numbers;

(*c*) actual departure time from the reference point;

(*d*) key for the headways at the observa-

tion point (reference point) and at the point where traffic is heaviest;

(*e*) the running times on each section of route at different times of the day;

(*f*) the sections of route and periods of time where standing passengers are not admitted.

Other data concern the length of the route and its different sections, the bifurcations and turning points.

On the strength of this considerable volume of data, timetables are drawn up which, apart from the basic interval of 20 or 30 min, are so flexible that the service offered is almost perfectly adapted to the traffic demand.

According to information supplied by the Baltimore Transit Company, the time required for compiling a timetable for one route is about 20 min. Because of this short period of time, it is possible very quickly to compile new timetables for all routes, for a group of routes or for a single route, and thus to adapt the timetables very promptly to any changes in traffic conditions which may occur during the normal validity period of a timetable.

Apart from the fact that the compilation of timetables is no longer a question of time, it is also possible to vary the timetables in many different ways, e.g. in accordance with the degree of passenger comfort. The Baltimore Transit Company restricts the number of passengers per bus to 60 during peak periods and to 45 during off-peak periods. The timetable would be different if these limits are varied to 55 and 40, respectively, or even to no more than 50 during the peak periods.

Although, as a result of such timetable variation, the economic efficiency of the undertaking might fall below the optimum, a new optimum may be obtained if, as a result of greater passenger comfort, additional traffic is promoted.

If passenger comfort is taken into account as a variable in the compilation of the timetables, this will obviously give rise to differences in the cost of the services provided and, hence, in the fares that must be charged.

Duty rosters.

The main problem inherent in the compilation of duty rosters lies in the technique of ensuring that the duty rosters of the vehicle crews exactly correspond to the vehicle rosters.

The duty roster should be compiled in such a way that, as far as possible, paid time is fully utilized for traffic duties.

However, for the following perfectly valid reasons, it is difficult to achieve this ideal:

(*a*) The compilation of duty rosters calls for a marked gift of coordination on the part of those entrusted with this work, which can be compared with the solving of a jig-saw puzzle. The compilers must divide the times shown in the timetables into shorter periods, and, instead of preparing a single roster for all the conductors of a train of vehicles, may even have to prepare different rosters for the conductors of the motor vehicle and those of the first and second trailers;

(*b*) When preparing the duty roster, it is often necessary to take into account greatly variegated and complicated working conditions governing the employment of the vehicle crews and the extent to which these can be utilised;

(*c*) Even slight modifications of the timetables may entail important changes in the duty rosters which upset the carefully built-up edifice of the latter and necessitate makeshift adjustments.

The application of electronic calculation and storage techniques will profoundly change the method of duty roster calculation, and the structure of the latter. It will now be possible to do what has long been done in industry: Work conventionally carried out by hand can be carried out more efficiently by machines.

As soon as the electronic data processing machines had been introduced on the Hamburger Hochbahn, we asked ourselves the following question: Will it be possible, in view of the large number of possible combinations affecting the duty roster, to prepare an ideal roster making allowance for working conditions? We examined this problem for a very long time, and with great care. Out of all the possibilities present we selected for the electronic solution a type of working model which might be termed « logico-topologic ».

The vital unit of this model is a basic value called « clock time duty ».

These clock time duties are abstract values. They merely represent an intermediate stage, serving as a link between timetables and duty rosters. They are nothing but periods of time. But these periods of time are so arranged, and so coordinated with the timetable, that they can directly serve as a convenient controlling variable. They shown in which combination of timings the actual duties must be arranged if the service requirements are to be covered by a minimum of staff.

The determination of the « clock time duties » is thus equivalent to the determination of the ideal division of time for the actual duties.

It is not possible to describe, in this report, the basic model and the sequence of electronically controlled operations involved in the preparation of the duty rosters. It is, however, relevant to point out that the clock time duties are based on the curve showing the number of vehicles in operation at any given time, a curve with peaks and deep valleys, well known to all transport experts. The clock time duties are determined by gradually reducing this curve.

For the compilation of the duty rosters, the following factors are being taken into account:

(*a*) the period of duty;

(*b*) the interval period;

(*c*) the restrictions on split-turn duties;

(*d*) the duration of breaks;

(*e*) the duration of duty stretches within the period of duty.

The electronic calculation programme is so arranged that these conditions can easily be varied.

With the determination of the « clock time duties », the first part of the electronic programme is concluded.

The second part consists in converting the « clock time duties » into actual duties.

The data required for this programme emanate from four sources; all of them are stored in the storage unit of the computer before the operations commence. They include:

(*a*) the timetable;

(*b*) the periods of time on the road between relief points;

(*c*) the signing-on and signing-off periods which must be taken into account with normal and split-turn duties;

(*d*) the « clock time duties ».

A decisive factor in the programme is the so-called « chain of compensation ». The purpose of this chain is to correct the periods by which the actual duties exceed, or fall short of, the clock time duties, in such a way that the structure of the pre-determined period of time required for the ideal duty roster is changed as little as possible.

The duty roster is not completed before the « duty staggering schedule » has been prepared.

This represents the third and last stage of the programme. The function of this schedule is to group the duties obtained in the previous stage in cycles of 7 to 14 actual duties, the aim being to effect this grouping in such a way that a complete cycle largely corresponds to the normal duration of work during one or two weeks.

Once more, this task is complicated by certain difficulties arising from the statutory working conditions. But here, too, it is possible to make use of logical principles which can easily be applied to the solution of the problem by electronic methods. This last stage of the programme concludes the automatic working cycle : The timetable has been converted into a duty roster.

Traffic surveys.

Already in the past, the evaluation of traffic surveys has been greatly aided by punchcard techniques. With the advent of electronic data processing machines, the importance of these techniques will be further enhanced, and the processing and evaluation of the data will be speeded up considerably. In particular, it will be possible to carry out more profound studies of the traffic problems and to find, for the purpose of traffic and transport planning, new solutions which, though also obtainable by means of conventional mechanical methods, could not have been obtained at an economically justifiable cost.

Turning, finally, to the more complex studies which clearly belong to the sphere of operations research, the report quotes the following examples :

Pre-determining the track renewal programme.

Inspired by the corresponding programmes of the FAC-TRONIC electronic installation of the Chesapeake and Ohio Railway Comp., Cleveland, the Hamburger Hochbahn has embarked on a « study concerning the pre-determination of the track renewal programme ».

The purpose of this study is to find out whether, and to what extent, it may be possible, with the aid of measurable technical variables and of the traffic density factors governing the degree of rail wear, to predetermine the dates at which it will become necessary for tramway track to be renewed. For the purpose of this study, it has been assumed that the electronic data processing machine would take charge of the extensive computing operations, and that the relevant data concerning the track installations as well as the relevant computing factors would be contained on punch-cards or in the electronic storage organs.

Among the vital factors having a bearing on the renewal schedule are :

(1) Density of traffic on the track, in tons per annum (a value which, in the case of electronically prepared timetables, can be derived from the timetable performance data);

(2) Rail material (e.g., ultimate strength, surface hardness);

(3) Type of rail (grooved rail, flat-bottomed rail, profile size);

(4) Material of the wheels;

(5) Type of vehicle (e.g. articulated vehicles);

(6) Sub-soil (e.g. grown soil, compacted soil, sand, clay);

(7) Substructure (e.g. concrete, stone packing, ballast);

(8) Type of construction (e.g. separate right-of-way or tracks embedded in the road surface);

(9) Up and down gradients;

(10) Position of the track in relation to the tram stops (braking section, starting section, running section);

(11) Type and volume of motor traffic;

(12) Rail grinding operations (e.g. to remove corrugations);

(13) Curve radii;

(14) Rail superelevation;

(15) Running speed;

(16) Meteorological factors.

The mathematical model for the calculation of the track renewal programme must be based on the following requirements :

(1) The calculation of rail wear in earlier periods;

(2) Departing from this calculation, it is necessary to ascertain the condition of the track at any given time, and the resulting track renewal requirements during the forthcoming financial year. This calculation can also be used for purposes of verification where the track renewal programme is based on practical experience;

(3) An assessment of the track renewal requirements in times to come and, in conjunction with this assessment, a pre-calculation of the dates at which the renewal will have to be carried out, and of the cost involved in each financial year. This calculation is handicapped by the fact that it is necessary to work with estimated traffic data and uncertain costs of materials and construction. It is therefore necessary for the calculations to be adjusted from time to time.

Our study has shown that, once the preliminary work has been completed and a computing programme has been compiled, the electronic data processing machine can be used to ascertain, at any time, the present and future track renewal dates without any major effort in terms of labour or time. At present, this only applies to straight track. The corresponding calculations for curved track, points and crossovers are considerably more difficult in view of the uncertainty of the technical calculation factors applicable to such track sections.

Analysis of traffic demand as a basis for the planning of transport routes and services.

The problem is not new. Up to now, however, the finding of an ideal solution has suffered from the inadequacy of the equipment available for the requisite calculating and selecting operations. With the advent of electronic methods, however, the possibilities have undergone a fundamental change.

Transport requirements consist of actual and latent demands.

The former can be ascertained from traffic surveys which should indicate :

(1) *where* the demand arises (geographical distribution);

(2) *when* the demand arises (distribution in time);

(3) *which fares categories* are involved (distribution in terms of revenue).

Like a flashlight exposure, the survey results indicate the present position. We recognize the traffic flows, the traffic concentrations and the focal points, the volume of transfer traffic from one vehicle to another vehicle of the same type, and from a vehicle of one type to a vehicle of another type, the distances covered by passengers, the distribution of passengers over the different fares categories, etc.

But these results do not exhaust the potentialities of traffic surveys. We must try and find the best possible way of meeting the traffic demand, the most efficient route layout and route alignments, and the most efficient way of using the means of transport available. We are thus confronted with an « optimum problem » which must be formulated mathematically or logically. If the problem can be solved by purely mathematical means, it would normally be advisable to resort to a standard model based on the linear programming method.

The construction of the model of the optimum system for the planning of transport routes and facilities becomes even more difficult if it is also necessary to include the latent demand in the system of investigation. The object of this calculation is to determine the potential traffic demand likely to arise as a result of service improvements, fares adjustments, publicity campaigns and other commercial measures.

Investigation into the optimum fares level.

It can hardly be claimed that the fares of public transport undertakings are based

on exact methods of scientific calculation and research. Apart from the fact that they are subject to political influences and have, under such political pressure, become distorted und un-related to actual costs, the fares have, at one time or other, been fixed by many undertakings on a more or less intuitive basis, and have remained in this form ever since.

With the advent of electronic data processing machines, the transport undertakings are now able to abandon the intuitive method of fixing their fares, and to resort to more scientific methods instead.

Research into the optimum fares level must consist of several stages :

During the *first stage,* it is necessary to determine, on the strength of the costing data available, the cost prices of the transport services offered. Non-relevant expenditure (exceptional expenditure, or expenditure not related to the time concerned, or to operation) can be eliminated from the study. On the other hand, additional costs not appearing in the costing calculations (e.g. interests on capital assets) must be added.

During the *second stage,* each cost item must be divided into a fixed price component and a variable price component. This analysis will serve to determine the cost of transport with different degrees of utilisation of the full service capacity (e.g. the costs per seat kilometre with 40 %, 39 %, 38 %, 37 % etc. utilisation of the operating capacity).

The object of the *third stage* is to determine the average receipts from fares, necessary to cover the cost price. It is at this stage that one is confronted with revenue estimates of different magnitude if, e.g., alternative timetables with different degrees of passenger comfort are being investigated. In the results obtained from the third stage of calculation, these comfort variables lead to different degrees of utilisation of the operating capacity. In practice, these degrees of utilisation are known as « percentage seat utilisation ».

On the strength of the amount, thus determined, of the receipts required to cover the costs, it is easy to determine the optimum fare structure (flat fare, sectional fare, etc.) as well as the optimum level of differential fares (reduced fares, preferential fares) which usually form part of the fare structure.

If it is intended to calculate such preferential fares on a sound costing basis, it is necessary to include in the programme not only the full costs but also the marginal costs; for it is these which represent the lower limit for reduced and preferential fares (social fares).

The calculation of marginal costs and minimum fares is, moreover, also required where operating or political considerations call for a departure from the normal cost price. This question may arise when new routes or novel types of transport are taken into operation where the full costs cannot be expected to be covered immediately by the revenue.

The costing and fares fixing programme has here been referred to in its simplest form only, and then only from the point of view of the actual costs. The matter becomes more complicated if the factors governing the demand are brought into play, such as the cost of living, the income and employment conditions of the population served, their way of life, the subjective value attached to transport services, and the competition to be faced. These political and economic factors which have a bearing on fare fixing, must reflect the present conditions, but must also take into account the probable future trend, as the fares of the public transport undertakings can, as a rule, not be altered at short notice.

* * *

In conclusion, the author of the report suggests that the public transport undertakings should concern themselves with the potentialities of automation and with the preparation of standard models which can be used for the analysis of, and closer investigation into, the problems concerned.

P. SCH.

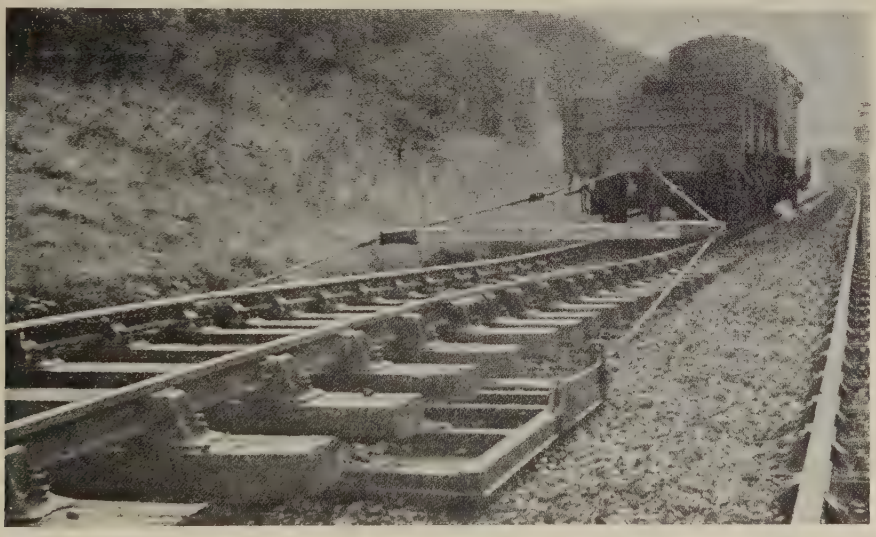
[625 .143 .5 (42)]

The A.D. rail fastening for concrete sleepers.

Development by British Railways, North Eastern Region, of fastening for track-circuited long-welded rails: improved method of re-laying.

(From *The Railway Gazette*, March 27, 1959.)

A new type of rail fastening, for use with flat-bottom rails and Class « F » concrete sleepers with modified rail seatings, known as the A.D. assembly, has been developed by Mr. A. Dean, Chief Civil Engineer, British Railways, North Eastern Region. After successful trials under exacting track conditions, 2 3/4 miles of concrete sleepered track with long-welded rails, using the new A.D. assembly, were laid in the main running lines on the North Eastern Region last year. A further 12 miles are scheduled to be laid during the current year.

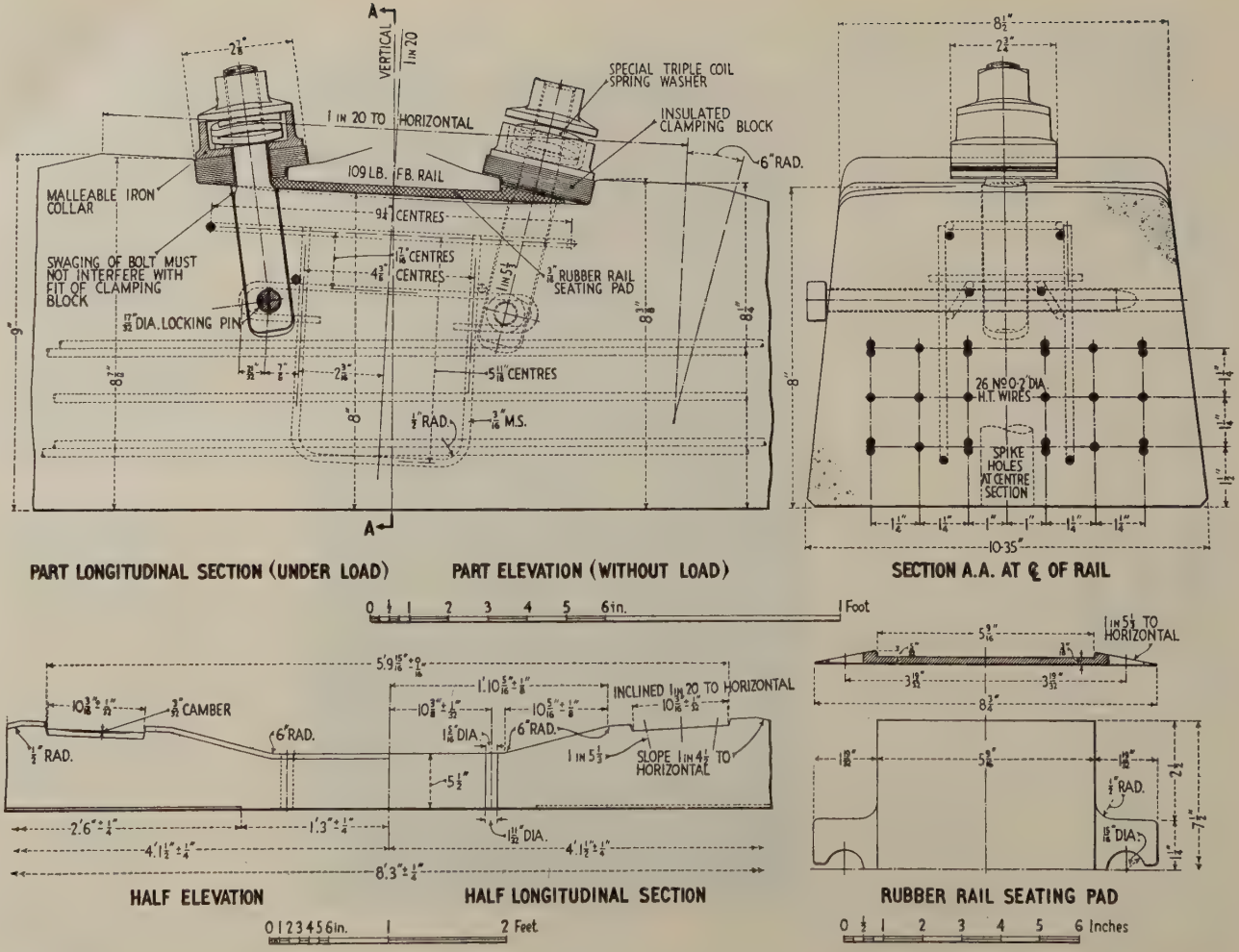


Towing ballast drag under the old sleepers in preparation for re-laying.

Assembly.

The assembly consists of an insulating clamping block, malleable cast-iron containing collar, and triple-coil spring washer. These are secured firmly in position against the rail foot by a holding-down bolt, tightened by a flanged nut and restrained by a locking pin which passes transversely through the concrete sleeper and also through a hole in the end of the holding-down bolt.

The rail is seated on a rubber pad 3/16 in. thick with retaining lug exten-


VERTICAL
1 IN 20
SPECIAL TRIPLE COIL SPRING WASHER
1 IN 20 TO HORIZONTAL
INSULATED CLAMPING BLOCK
6" RAD.
109 LB. F.B. RAIL
MALLEABLE IRON COLLAR
9½" CENTRES
SWAGING OF BOLT MUST NOT INTERFERE WITH FIT OF CLAMPING BLOCK
17/32" DIA. LOCKING PIN
RUBBER RAIL SEATING PAD
5 11/16" CENTRES
½" RAD.
3/16" M.S.
26 No 0·2" DIA H.T. WIRES
SPIKE HOLES AT CENTRE SECTION
10·35"
PART LONGITUDINAL SECTION (UNDER LOAD)
PART ELEVATION (WITHOUT LOAD)
SECTION A.A. AT ℄ OF RAIL
0 ½ 1 2 3 4 5 6in. 1 Foot
3/8" CAMBER
INCLINED 1 IN 20 TO HORIZONTAL
1 IN 5⅓
SLOPE 1 IN 4½ TO HORIZONTAL
1 IN 5½ TO HORIZONTAL
HALF ELEVATION
HALF LONGITUDINAL SECTION
RUBBER RAIL SEATING PAD
0 1 2 3 4 5 6in. 1 2 Feet
0 ½ 1 2 3 4 5 6 Inches

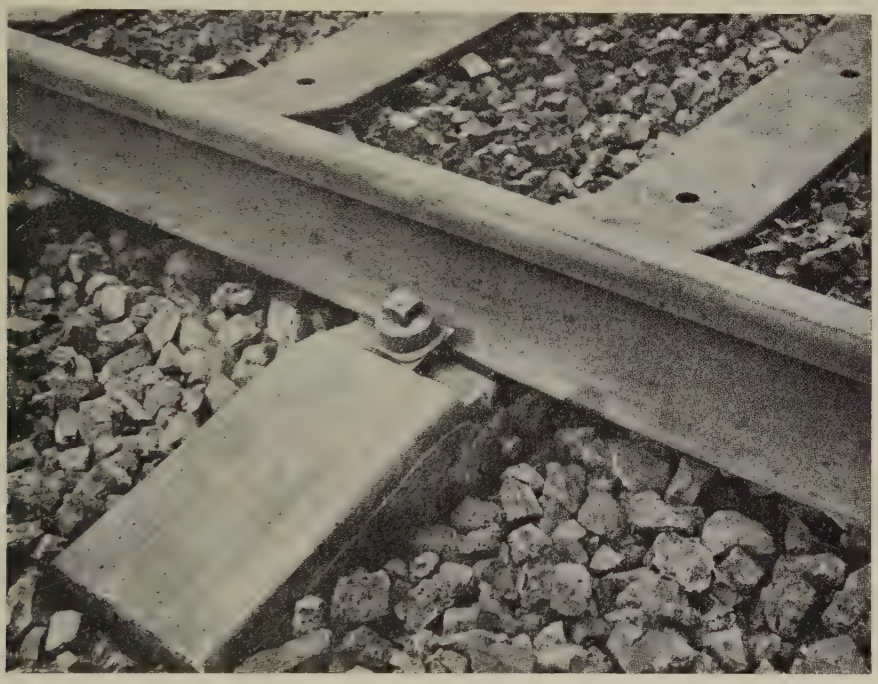
Details of A.D. assembly for fastening flat-bottom rails to concrete sleepers.

sions which fit snugly round the holding-down bolt and up to the sides of the rail foot.

A feature of the assembly is the standard of tension maintained in both static and dynamic conditions. This is achieved by the inclusion of the special triple-coil spring washer which provides, within practical limitations, for applied bolt loadings to accord with the deflection characteristics of the spring washer.

The spring washer is housed in the malleable iron collar, the internal depth of which has been determined by the free height of the washer and the extent to which it must be compressed so as to transmit the bolt loading through the containing collar and clamping block to the foot of the rail.

Tensioning of the assembly is achieved by tightening the flanged nut of the holding-down bolt so that when the nut contacts the upper circumferential surface of the containing collar, the necessary static loading is applied. Under dynamic loadings imparted by traffic, slight resilient deformation of the rubber pad occurs, but relative tightness of the fastening on the rail foot is retained by the reaction of the coil spring washer. Experience has shown that maintenance attention to loose fastenings is negligible.



A.D. fastening in position, showing locking pin passing transversely through sleeper, and holes in centre line.

Clamping blocks and seating pad.

The clamping blocks are machined from laminated resin-bonded beechwood. With the natural rubber rail seating pad, they ensure the electrical insulation of the rail. The rubber pad is designed to take up

the shear stresses in the rubber when subjected to impacting traffic loadings and so avoid, or minimise, abrasive wear of the pad.

The spring washers are helical springs of rectangular section with triple coils. Each coil has an additional set which, besides the ordinary deflections, gives an increased tensioning capacity. The containing collar is in blackheart malleable iron, shaped to fit over the insulating clamping block and is treated with a protective coating against rust.

The holding-down bolt is of steel and housed in an inclined hole in the concrete sleeper. The bolt is 1 1/8 in. dia. swaged down to 7/8 in. at the screwed end. Holding-down bolts and locking pins are treated at the time of assembly with a bitumen sealing compound to prevent corrosion and seizing.

The components lend themselves to simple assembly and are easy to replace. There is the further advantage that this fastening, as regards insulation of track circuits, is more acceptable to the signal engineer than many others.

The designed nominal gauge for 109-lb. flat-bottom rails is 4 ft. 8 7/16 in. and resistance to lateral movement of the rails relative to each other is supplemented by the bearing of the insulating clamping blocks against the shoulders of the sleepers. Additional resistance to any possible lateral track movement can be provided, should the need arise. There are two 1 5/16 in. dia. holes in the sleeper on the centre line position in the 4-ft. way to take spikes of suitable length which can be driven through into the ballast. These holes can also be used for fixing A.T.C. apparatus, if required, without using special sleepers.

Morris tracklayer placing 30-ft. track section in position.

Improved re-laying methods.

« F » concrete sleepers, delivered in trainloads to the permanent way depot, are unloaded on to assembly grids, where, with 30-ft. 109-lb. flat-bottom rails, they are prefabricated into 30-ft. track sections; 30-ft. service rails, with the rail fastening components, are stacked adjacent to the grids. Both sleepers and rails are placed in their relative positions by an overhead travelling gantry crane. The rail fastenings are fitted by hand and final tightening of the flanged nuts is by air-operated impact wrenches.

The prefabricated sections are then loaded by the overhead gantry into track carrying wagons which are made up into trainloads for moving to the renewal site. Up to 1 200 track-yd. can be carried in one train.

When possession of only the one line to be renewed is available, as is likely to be the case more frequently in future traffic conditions, the old track is removed in sections, usually 60 ft., and replaced by new 30-ft. concrete sleepered sections laid in by the Morris tracklaying train. When this is used, it is necessary for a self-propelled trolley fitted with two powered circular saws to follow the ballast drag and cut the ends of the old sleepers to 8 ft. 5 in. for handling through the Morris train.

When possession of two tracks can be obtained, the old track is removed by a travelling rail crane and the new track laid in by a twin-jib tracklaying crane. By this method the twin jib crane has to lay twice as many 30-ft. sections as the travelling rail crane removes 60 ft. sections; but because of the faster rate of laying by the twin jib crane, a reasonable balance between the two units is attained and average speeds of laying of 170 track yd. per hr. are achieved. New ballast is then tipped from a ballast train of hopper wagons to give additional track lift, fill in the beds between the sleepers, and provide a 12-in. shoulder of ballast outside sleeper ends.

The new track is then lifted to final level by track jacks and slewed to final alignment by steel bars. The ballast under the sleepers and for about 9 in. on either side of each rail, is consolidated by a ballast tamping machine.

After the new fabricated track has been laid for a week, the temporary service rails are removed and 300-ft. long welded rails substituted. The latest, and somewhat novel method, adopted in this operation was described in our issue of November 21, 1958.

The A.D. fastenings, except bolts and locking pins, have to be removed from the short service rails to permit the rails being tipped manually into the 4-ft. way, and replaced after the long-welded rails are laid in. The unscrewing and retightening of the flanged nuts is by impact wrenches powered by small mobile air compressors.

Short service rails, after being carried out manually into the 6-ft. way, or cess, are picked up by small cantilevered cranes mounted on rail-carrying wagons and taken to the depot for re-use.

[625 .17 (52)]

The work intensity and the rationalization of track maintenance operations,

by Motoshi Hida,

(Translated from « Tetsudo Senro », *Bulletin of Permanent Way Society of Japan*, Vol. 6, No. 8, Aug. 1958).
(From the « *Permanent Way* », No. 3. Nov., 1959).

Summary.

The operations of trackmen are one of the heaviest physical kinds of work in which the factor of work which is not heavy is very small. However, the intensity of the operations of trackmen has hitherto been unknown. The author of this report has conducted investigations and tried to furnish basic data for the rationalization of labor in the track maintenance operations.

In the track maintenance operations the factor of static work is small, and the dynamic work which puts all the muscles of the body into action is predominant. Accordingly, the work intensity to the track maintenance operations can be measured by the amount of energy consumption. The author measured the amount of energy consumption, and detected that the average rate of energy consumption in the track maintenance operations including recesses is 5 to 6, that the amount of energy consumption in working is 2 800 to 3 000 calories and the entire energy consumption of a trackman in living a home life is 3 800 to 4 000 calories a day. Since the physical limit of daily energy consumption is 4 000 calories, the rationalization of labor must be carried out.

In order to carry out the rationalization of track maintenance operations :

1. Action norms of minimum fatigue should be fixed,

2. The operation norms which avoid waste of labor should be fixed,

3. The operations should be mechanized, and the adjustment of labor should be made so that operations may be kept at a high level of efficiency for many hours and the reproduction may be perfect.

1. Foreword.

The work of a trackman may seem a simple labor of bending and stretching arms vertically or laterally, with a hammer in hand, but on closer examination it is a complex labor accompanied with a relatively high degree of brain work and is one of the heaviest kinds of physical work in the operations in the J.N.R.

Now that many kinds of work are being mechanized, most part of the field operations still remain a heavy physical labor, and there are few kinds of field work which are not heavy.

The intensity of track maintenance operations was hitherto unknown. In order to obtain basic data for rationalizing the track maintenance operations, the present writer measured the relative metabolic rates in various kinds of work involved in such operations. Now he is going to state briefly the results of this investigation.

2. The relative metabolic rates (R.M.R.).

Generally speaking, in rating the work intensity of any kind of operations, the operations under survey should be examined as an integral whole, namely, all the factors constituting the operations — the factor of brain work, the factor of physical work and the stress from environments — should be taken into

consideration. The track maintenance operations, however, consist principally of dynamic kinds of work which put all the muscles of the body into action. The static element is very small and negligible in track maintenance operations. Accordingly, the intensity of the operations is rated by the amount of energy consumed. The track maintenance operations are physical labor.

In a human body two main internal activities are incessantly going on. One is the activity necessary for keeping cellular vitality and progresses ceaselessly whether one is awake or asleep or one is working or resting. This activity is called basal metabolism. The other is the metabolism from working and is called labor metabolism or the energy metabolism of labor.

In basal metabolism just that much energy is consumed as necessary to maintain vital cellular activity, and such energy consumption is measured when one is in the fasting or resting state, for instance, when lying on bed ten to fifteen hours alfter meal and one has sufficient nutriment in itself and uses just enough energy to maintain life. On the other hand, the metabolism of energy necessary for or accompanying labor is the labor metabolism, and its ratio to basal metabolism is called the relative metabolic rate, and this rate is expressed by the following formula :

$$\frac{\begin{pmatrix}\text{Amount of relative}\\ \text{metabolic rate in work}\end{pmatrix} - \begin{pmatrix}\text{Amount of relative}\\ \text{metabolic rate in rest}\end{pmatrix}}{\text{Basal metabolism}} = \frac{\text{Labor metabolism}}{\text{Basal metabolism}} \quad \ldots \quad (1)$$

Basal metabolism is the consumption of energy necessary for the maintenance of life and has no relations with the external actions of the body. It differs according to the stature, weight, the body surface area, age and the sex of an individual and the external conditions such as temperature. The different ratios are proportioned to the amount of metabolism in rest and the total energy consumption. Accordingly, these values are used to express the intensity of any kind of labor and are made the data for energy consumption.

In Formula (1) the amount of energy consumption in rest is the amount of metabolism in the state of being ready to work. Namely, one does not start working immediately from the posture in which basal metabolism only goes on but

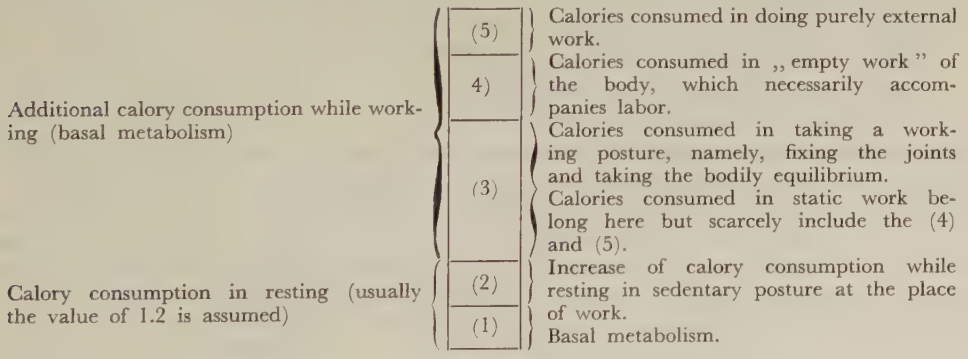

Additional calory consumption while working (basal metabolism)
Calory consumption in resting (usually the value of 1.2 is assumed)
(5)
4)
(3)
(2)
(1)
Calories consumed in doing purely external work.
Calories consumed in „ empty work " of the body, which necessarily accompanies labor.
Calories consumed in taking a working posture, namely, fixing the joints and taking the bodily equilibrium.
Calories consumed in static work belong here but scarcely include the (4) and (5).
Increase of calory consumption while resting in sedentary posture at the place of work.
Basal metabolism.

Fig. 1.

starts working from a sedentary or standing posture in which a certain additional metabolism takes place consuming a certain additional amount of energy. The metabolism in this « preparatory posture » is 125 % of the amount of basal metabolism for a man and 115 % for a woman. Here the ratio of 1.2 is assumed. Figure 1 explains this situation.

The sum of labor metabolism and metabolism in resting is called the work intensity, and the product of a mass of the work intensity and the working hours is called the work index.

3. The computation of the relative metabolic rate.

The relative metabolic rate is computed by Formula 2.

$$\text{Amount of energy consumption} = \text{Amount of basal metabolism} \times \text{body surface area} \times (\text{metabolic rate} + 1.2) \times \text{working hours.} \quad \ldots \quad (2)$$

TABLE 1. — **The average amount of basal metabolism of a Japanese.**
(in calories/square meters/hours)
(according to the Ministry of Health & Welfare)

Age	Male	Female	Age	Male	Female
15	39.45	36.20	20	36.80	33.75
16	38.50	35.20	21～30	36.71	33.06
17	37.75	34.00	31～50	35.88	31.82
18	37.25	34.00	51～60	34.44	31.23
19	37.00	33.75			

TABLE 2. — **The average body surface area of a Japanese.**
(in square meters)

	Weight							
Stature	40	45	50	55	60	65	70	75
140	1.25	1.31	1.38	1.43	1.49	1.54	1.59	1.63
145	1.28	1.35	1.41	1.47	1.52	1.58	1.63	1.68
150	1.31	1.38	1.45	1.51	1.56	1.62	1.67	1.72
155	1.34	1.42	1.48	1.54	1.60	1.66	1.71	1.76
160	1.37	1.45	1.52	1.58	1.64	1.69	1.75	1.80
165	1.40	1.48	1.55	1.61	1.67	1.73	1.79	1.84
170	1.44	1.51	1.58	1.65	1.71	1.77	1.83	1.88
175	1.47	1.55	1.62	1.68	1.75	1.81	1.89	1.92

The metabolic rate + 1.2 represents the above-side work intensity. The amount of energy consumption in rest hours is estimated to be 1.2 times as much as that in basal metabolism.

$$A = W^{0.427} \times H^{0.718} \times 74.49$$

The amount of basal metabolism of a Japanese, shown in Table 1, and the average body surface area of the same, shown in Table 2, were figured out from Dr. Takahira's Expreimental Formula 3.

$$\begin{aligned} A &= \text{body surface area} \\ W &= \text{weight} \\ H &= \text{stature.} \end{aligned} \quad \ldots \quad (3)$$

4. Classification of work.

Work is generally divided into heavy work, medium work and light work, and the work which consumes 3 000 calories a day of energy or which increases the metabolic rate to more than 4 is considered as heavy work. Physiologically work is classified as Table 3 shows.

TABLE 3.

Classification	Metabolic rate
Very light work	0～1
Light work	1～2
Medium work	3～4
Heavy work	4～7
Severe work	Above 7

TABLE 4.

Vocation	Relative metabolic rate	Work or action	Relative metabolic rate
Typist	1.9	Sedentary	1.4
Shoemaker	2.4	Standing	1.6
Blacksmith	3.2	Walking	2.4
Mason	5.2	Running	6.0
Clerk	2.0	Taking a meal	1.4
Bookbinder	2.3	Dressing oneself	1.4
Carpenter	3.2	Sewing	1.4
Painter	3.2	Operating a sewing machine	1.6
Woodcutter	3.2	Sleeping	0.8
Trackman	5～6		

According to another classification, work is divided into heavy muscular work, continuous work and light speedy work. Table 4 shows the metabolic rates in different vocations and different kinds of operations.

5. The human efficiency.

In heavy muscular work in which the relative metabolic rate exceeds 4, the factor of static work is small and the factor of heavy dynamic work which puts every muscle of the body into action is predominant. Accordingly, in such a kind of work the fatigue can be measured by the amount of energy compensation.

The rationalization of such work from the physiological standpoint should be aimed at preparing conditions under which the work can be done with minimum energy consumption. Efficiency is regarded as the most important feature of a machine. In the case of human labor the rate of the amount of work done to the amount of energy consumed may be regarded as the efficiency of a worker. Namely,

$$\text{Human efficiency} = \frac{\text{The amount of work done externally}}{\text{Labor metabolism}}$$

When the amount of work is fixed, smaller the energy consumption is, the better the efficiency is regarded to be.

6. The work intensity of track maintenance operations.

The purpose of the track maintenance operations is to lay a track and secure the safe and punctual operations of trains. Unlike the case with factory work, the

Photo 1. — Ballast work (screened ballast).

measurements of quality is difficult. What is more, the track maintenance operations involve geographical and/or physical factors such as the structure of the track, the quality of the road bed, and the geographical feature and weather conditions. It is very difficult to grasp theoretically the substance of the operations.

Because, as stated above, heavy muscular work is a predominant factor in the track maintenance operations, the basis for the rationalization of labor can scientifically be obtained from the amount of energy consumption.

Table 5 shows the work intensity of track maintenance operations revealed as a result of investigation by the Kisarazu Track Maintenance Office in 1952 and 1953, conducted with guidance and cooperation by the Health Control Office.

The operations shown in Table 5 belong to heavy work or severe work, and the average rate of metabolism of a trackman during the working hours including a recess is estimated at between 4 and 6. Assuming that the average metabolic rate is 5 and adopting the numerical values shown in Table 1, the amount of energy consumption of a trackman during the working hours is 2 800 to 3 000 calories and the amount of energy consumption of the same person in living a home life is 3 800 to 4 000 calories a day. The calory intake of an average Japanese is 2 400 to 2 700 calories a day. Accordingly, the amount of energy consumed in working by a trackman is equivalent to the afore-said amount of energy consumed in a day for living a home life.

From the table hereafter it is clear that the work of a trackman is of the same intensity as running continuously. The energy consumption of 4 000 calories a day is considered to be the physiological limit, and

Photo 2. — Tamping ballast with beater.

the trackmen are doing physical labor which imposes energy consumption of this very limit.

From Table 5 it is clear that the sleeper replacement work by lifting is heavy work of metabolic rate of 5,3 and the sleeper

TABLE 5. — **The metabolic rates of track maintenance operations.**

Examinee	Work	Relative metabolic rate	Remarks
A	Sleeper replacement work by lifting	5.2	Done by 2 person:
C	Same	5.4	Same
A	Sleeper replacement work by tamping	5.5	Same
C	Same	6.3	Same
A	Ballast removal (broken stone)	7.8	
A	Ballast refilling (»)	8.2	
B	Ballast removal (»)	7.3	
B	Ballast refilling (»)	7.6	
AB	Ballast removal (screened gravel)	7.4	
B	Ballast refilling (»)	7.2	
A	Ballast removal (»)	7.0	
A	Ballast refilling (»)	7.2	
D	Ballast tamping with a tamper	3.7	Done by 4 persons
A	Same	3.1	
D	Same	4.0	
A	Ballast tamping with a beater	5.5	
D	Same	5.8	
A	Dogspike driving	8.0	
A	Dogspike pulling	9.2	
A	Alinement	6.6	
A	Ballast screening (screened gravel)	7.2	

Photo 3. — Tamping ballast with tamper.

replacement work by tamping is also heavy work of metabolic rate of 5.9 The lifting method is of a lower metabolic rate than the other and requires less working hours. Accordingly, the lifting method with a lower work index is superior, both physiologically and physically, than the tamping method. In either case the trackman should be given a recess of about a quarter of an hour after every 50 to 60 min, and five to six hours a day of working are the most recommendable working hours for efficiency.

Ballast removal, ballast refilling and ballast screening are all severe labor of

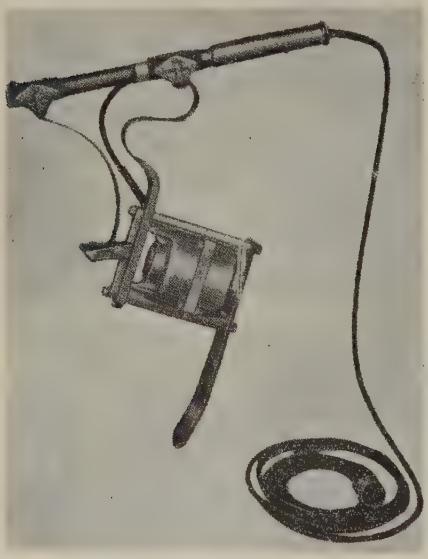


Photo 4. — Temper.

metabolic rates of more than 7. In case of using broken stone, these categories of work are of greater intensity than when gravel is used. In either case continuous working is difficult. The working hours should be three to four hours a day at most and should not exceed five hours for efficiency's sake.

The metabolic rate of ballast tamping is 5.5 to 5.8 if done with a beater and 3 to 4 if done with a tamper. The use of a tamper is far more efficient. Tamping with a beater is of the same category as sleeper replacement work in respect of work intensity, but tamping with a tamper is lighter work than that.

Alinement is of approximately the same metabolic rate as tamping with a beater and accordingly is heavy labor.

7. The rationalization of labor.

The author wishes to discuss the track maintenance operations in fuller detail on next occasion.

The rationalization of labor is an essential factor in business rationalization. True rationalization of labor is not to seek the maximum amount of operations within minimum working hours but is to prepare such working conditions as make it possible to attain the highest possible output, both in quality and in quantity, without difficulty or, in other words, to enable every worker to display his ability with the highest efficiency.

Such conditions are prepared by doing as follows :

1. To station each worker in the fittest position (to allot fittest work to each worker).

2. To mechanize such kinds of work which consume much energy or cannot be separated from harmful working conditions.

Work whose metabolic rate is high — such as severe or heavy work — or harmful or unsanitary work must be mechanized. Work with shovels or hammers should be done by machinery. Workers should not be forced to take unnatural postures or make unnatural movements or subjected to moral-nerve tension.

3. To find out a psychological attitude or behaviour in which fatigue is reduced

to minimum. To avoid waste of labor by fixing efficient working postures or action standard.

4. To study and find out the most efficient orders and methods of operation. To avoid waste of energy in proceeding from one kind of work to another. To increase the productivity of labor by fixing a highly efficient working norm.

5. To give recesses at proper intervals and fix rational length of working hours and norms.

In accordance with the intensity of each kind of operation, brief breaks and recesses of proper length an frequency should be given. Recovery from fatigue and spiritual weariness should be given in order to prevent the deterioration of efficiency. Namely, the adjustment of labor should be made so that labor power may be kept in a highly efficient state for many hours and the reproduction may be perfect.

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[656 .225]

Use of containers for all merchandise traffic.

Proposed method of improving service by using self-propelled transfer cars to move containers on and off set trains of flat wagons.

(By a correspondent.)

(*The Railway Gazette*, January 8, 1960.

It is generally recognised that though a railway train is a more efficient method of transport than a road vehicle, it nevertheless has two main disadvantages. First, door-to-door service is not possible without special equipment. Second, the inherently efficient operation only begins when the traffic has been formed into a train and ends when the train has to be broken up. Extensive improvement in the railways' position as regards traffic which is vulnerable to road competition therefore involves not only the road-rail transfer problem, but also better methods of moving individual consignments on and off trains.

To enhance the loadability of traffic to be moved by rail three requirements are dictated by consideration of first principles. First, all possible traffic must be contained in standard packages equipped with suitable fittings on the outside for engagement by the handling equipment — in short, use containers. Second, suitable flat wagons must be provided. There is no question of a particular type of container needing a particular type of wagon; complete interchangeability is essential. The third requirement is equipment which will move containers quickly and cheaply on and off wagons. All existing methods of doing this are much too slow in operation to exploit adequately the advantages of the container and flat wagon principle. Furthermore, they all need a fixed installation, be it only a good road surface from which to work, and lack the mobility and versatility.

A container-mover without these disadvantages, and generally suited to rail-way conditions, would not only go far to solve the road-rail transfer problem, but in addition, if the flat wagons were formed into set trains covering the country rather in the manner of intersecting conveyor belts, it might be feasible to move containers from train to train en route and so eliminate the disadvantage of shunting. If the capital and operating costs were low enough it should be possible to at least equal the flexibility and the standard of service of road haulage and to provide it at less cost.

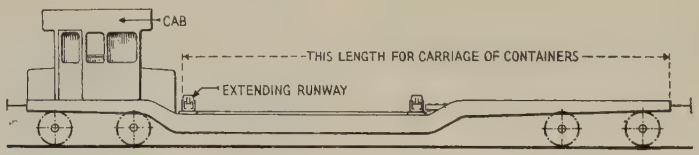

Fig. 1. — Elevation of transfer car, showing position of runway.

Proposed system for general merchandise.

A new system, termed « containerisation » for the purposes of this article, is

here assumed to be applied only to general merchandise on British Railways, but it can be adapted to most other goods traffic in Britain and overseas.

The containers can be transported on railway flat wagons or ordinary flat-platform road vehicles, or they may be stood on fixed stands whilst being loaded or unloaded or during sorting. The base of each container is one of a few standard sizes and has standard fittings such as mounting feet and locking gear. Lifting is from the base. The upper structure may be of any size and shape within reason and the loading gauge. The railway wagons are specially constructed bogie flat vehicles, equipped with power brakes and screw-coupled into block trains to run on fast schedules separate from other traffic. Coupling and uncoupling are less frequent than in passenger train operation. Sorting or marshalling by shunting is unnecessary.

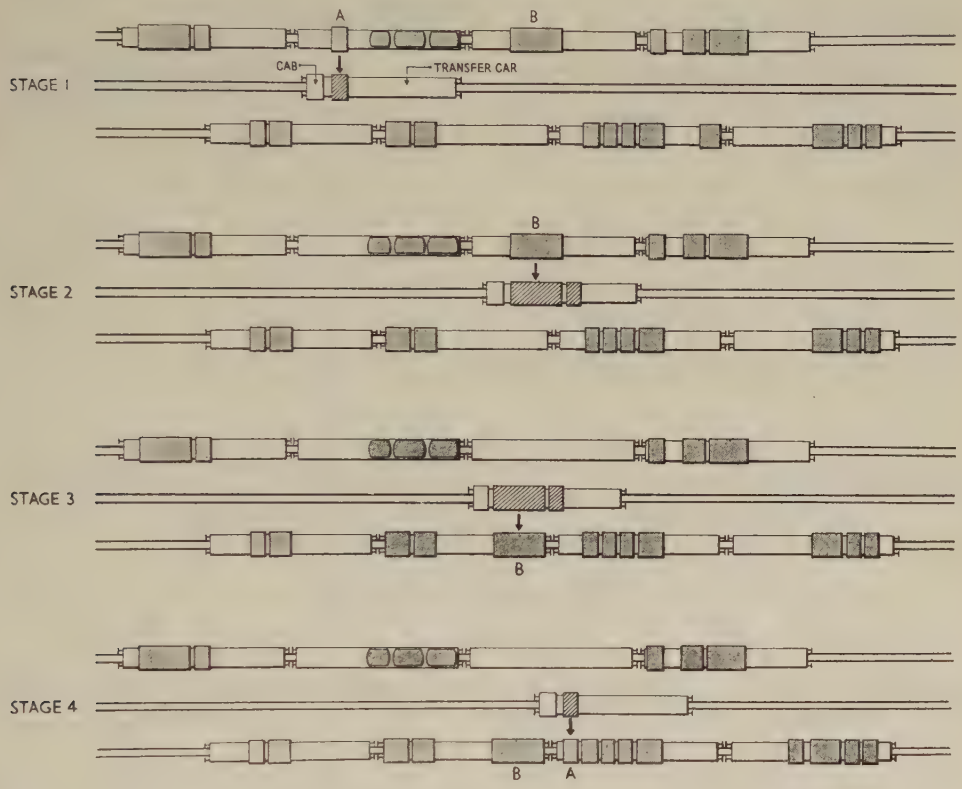

Fig. 2. — Transfer of containers « A » and « B » from one train to another, shown in four stages.

Containers moved sideways.

The containers are moved sideways on or off the road or rail vehicle (or fixed stand) by a special key vehicle, the « transfer car », illustrated in figure 1, and the basis of the system. In essence it is a Diesel-driven bogie wagon which carries several containers and is equipped with mechanism for moving one container at a time either on or off an adjacent vehicle

or stand. It is about 60 ft. long, weighs about 25 tons light and 60 tons with a full load of containers and can travel at about 50 m.p.h. on the main line under its own power. One man can operate the transfer car without leaving his cab.

container is moved from the transfer car to the other vehicle or vice versa in less than 10 sec.

Each block train has a loading list, compiled in the first place by the transfer car drivers at the start and kept up to date

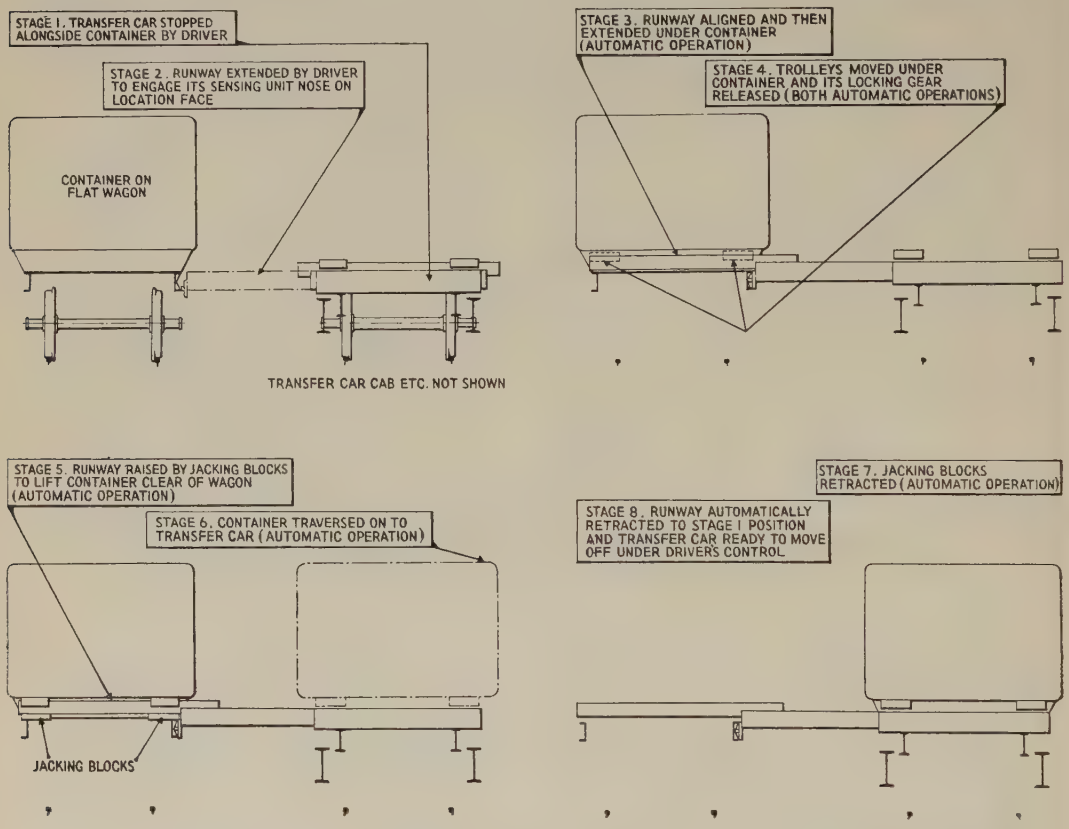
STAGE 1. TRANSFER CAR STOPPED ALONGSIDE CONTAINER BY DRIVER
STAGE 2. RUNWAY EXTENDED BY DRIVER TO ENGAGE ITS SENSING UNIT NOSE ON LOCATION FACE
CONTAINER ON FLAT WAGON
TRANSFER CAR CAB ETC. NOT SHOWN
STAGE 3. RUNWAY ALIGNED AND THEN EXTENDED UNDER CONTAINER (AUTOMATIC OPERATION)
STAGE 4. TROLLEYS MOVED UNDER CONTAINER AND ITS LOCKING GEAR RELEASED (BOTH AUTOMATIC OPERATIONS)
STAGE 5. RUNWAY RAISED BY JACKING BLOCKS TO LIFT CONTAINER CLEAR OF WAGON (AUTOMATIC OPERATION)
STAGE 6. CONTAINER TRAVERSED ON TO TRANSFER CAR (AUTOMATIC OPERATION)
JACKING BLOCKS
STAGE 7. JACKING BLOCKS RETRACTED (AUTOMATIC OPERATION)
STAGE 8. RUNWAY AUTOMATICALLY RETRACTED TO STAGE 1 POSITION AND TRANSFER CAR READY TO MOVE OFF UNDER DRIVERS CONTROL

Fig. 3. — Stages in traversing container from flat wagon to transfer car.

Figure 2 shows the procedure for the transfer of two containers only, but the transfer car will normally be loaded to capacity before unloading commences. The car stops alongside the container to be transferred, traverse it on to itself, and, after picking up other containers, runs alongside the first road or rail vehicle (or fixed stand) at which a container is to be deposited, and leaves it there. The during the journey. Each flat wagon in a train has an easily seen serial number which the transfer car drivers use in conjunction with the loading list to identify individual containers.

Automatic transfer of containers.

The method by which a container is traversed from a flat wagon (or road vehicle

or fixed stand) on to the transfer car is shown in stages in figure 3. The car has two runways which can be extended laterally on one side or the other to form a bridge to support four small trolley which actually carry the container.

The runways consist of three sections and are both mounted on a common sub-frame which can be raised or lowered or tilted slightly by hydraulic jacks to match variations in the level of the flat wagon. The centre section of each runway has a sensing unit at its end designed to engage with a location face on the wagon.

along the transfer car to suit the different lengths of container and is positioned by pushing the appropriate button.

Because of their high productivity, relatively few transfer cars are needed to mechanise handling of traffic.

Road-rail-transfer in depots.

The use of the transfer car to move containers between block trains and road vehicles needs little further explanation. The latter must have flat platforms and be fitted below with the indispensable

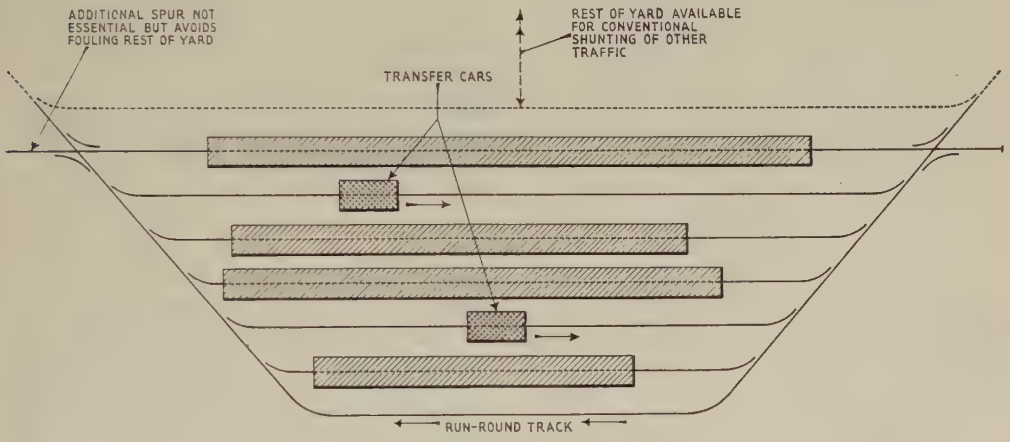
ADDITIONAL SPUR NOT ESSENTIAL BUT AVOIDS FOULING REST OF YARD
REST OF YARD AVAILABLE FOR CONVENTIONAL SHUNTING OF OTHER TRAFFIC
TRANSFER CARS
RUN-ROUND TRACK

Fig. 4. — Transfer cars working on four trains at once, using part of yard as transfer point. No container park is shown.

The driver initiates this engagement by stopping the transfer car so that when he partially extends the runway the sensing unit nose contacts the location face not more than 9 in. from its centre (stage 2 on fig. 3). This is facilitated by rail movement of the car being controlled below about 6 m.p.h. by a single forward-stop-backward lever. The remaining operations shown in stages 3 to 8 on figure 3 are automatic and the container is moved entirely without shocks. The car is ready to move off again within 10 sec.

A necessary feature, not illustrated, is that one extending runway can be moved

location face. The block train can, if necessary, remain a considerable distance from the road vehicle, for the transfer car will quickly convey several containers at a time from one to the other.

Each depot has some fixed stands of steel or concrete where containers can be parked if they have to wait for the road or rail vehicle. This avoids immobilising the transfer car. When necessary, containers can be moved between road vehicle and fixed stand by a light type of runway which can be readily carried in sections by hand.

No alteration to layout in the depot or

its sidings should be needed and civil engineering work should be restricted to the possible strengthening of loading platforms and the erection of the cheap and simple fixed stands.

Train-to-train transfer.

Whilst the transferring of containers from train to train may sometimes take place at depots it will usually be done elsewhere, corresponding to the present movement of wagons in marshalling yards.

The points in the yard can readily be arranged for operation by the transfer car drivers without leaving their cabs. A further saving in shunting staff accrues because couplings and brake pipes are already connected. When the transfer car has moved the last container the train can depart.

Several developments of the above are possible to suit different conditions. A container park of fixed stands can be placed alongside some of the sidings to permit containers being held for a time

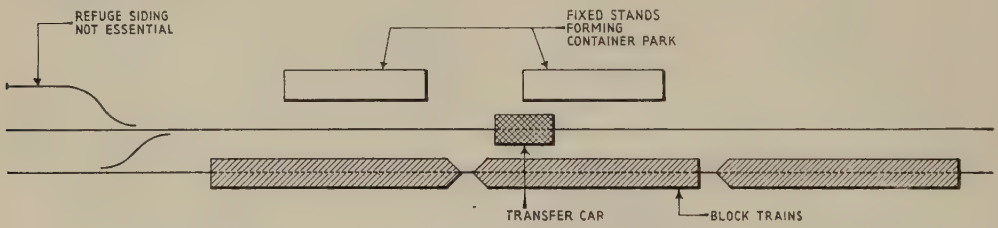

Fig. 5. — Minimum requirements for a transfer point. Container park is not essential if trains can all stand together at the same time.

The obvious choice for such a transfer point would be a set of sidings, either on their own or forming part of a much larger yard. Figure 4 shows an example of the latter with two transfer cars working simultaneously on four block trains; the numbers of each may naturally be increased if more sidings are in use. Each transfer car can not only move containers between the two trains adjacent to it, but can also take a load on to the siding between the other two trains and work on them also. Whilst hardly justifiable for only two cars, one of the sidings is shown reserved as a run-round track to allow circulation on a one-way traffic basis.

It might well be thought that even with the help of the train loading lists already mentioned, it would be inadvisable to have several transfer cars working simultaneously on several trains; but with loading lists and a simple set of rules developed on a model, the necessary procedure can soon be mastered and efficient operation should result.

without detaining any flat wagons. A mobile container park, made up of old four-wheel wagon underframes fitted with the standard container carrying gear, could be used to reduce the transfer car movements by being loaded up on one track and moved on to a siding adjacent to other trains for unloading.

Minimum of fixed equipment.

The absolute minimum of trackwork needed for a transfer-point is shown in figure 5. The two tracks might well be running lines if other traffic is light enough to give an interval of, say, 20 min for the block trains to stand close together whilst the transfer car is at work. If the trains cannot all be brought in at the same time a park would be essential.

Between these two extremes, variations are possible. The flexibility of the system is shown by the manner in which a little-used piece of track can come to life as a transfer-point for, say, 30 min every few

hours. Furthermore, as no track alterations are necessary, such transfer-points can be moved to cover variations in traffic. Except when a container park is needed, all equipment is on wheels. No difficulties arise as regard staff, for they too are conveyed in wheeled vehicles, arriving and departing with the block trains and transfer car.

Block train services.

As there is wide choice in the geographical location of transfer-points, scheduling of a suitable network of block train services should present little difficulty. Rather than trying to give each of the larger destinations its own train as at present, « Containerisation » traffic should generally be conveyed by the first train going in the required direction, so giving a more frequent service with far less than a *pro rata* increase in the number of trains run.

Only the use of the three main items of equipment has been mentioned, but many variations to suit particular conditions are perfectly feasible. For example, a combined locomotive and transfer car could be provided for working feeder trains serving small depots. Container handling by crane or fork-lift truck might be justified in certain circumstances, provided that the advantage of the proposed method, of smooth, shockless transfer is not violated. Another variation could be the running of one or two flat wagons attached to a passenger train, a revival of the now-defunct mixed train.

Reliability of equipment.

The production of reliable equipment would necessitate the building and thorough testing of prototypes. The mechanism of the transfer car would probably be subjected to the equivalent of a year's operation (say, 300 000 on-off cycles) several times to eliminate any initial troubles. This would not be a quick process even with accelerated testing methods, but neglecting it would only ensure future trouble.

Possible objections.

It can be objected that use of containers has not stopped the fall in traffic, and that they cannot be used for all traffics. The answer is that, as used at present, the only real advantage afforded by the container is door-to-door service. Its potentialities are only fully realised if it is used as an integral part of the whole « containerisation » system, when a better service is provided for the trader, and from the railway point of view, the carriage of almost all consignments, including even sundries, benefits. The present extra charge to the trader would not be needed.

Almost everything that can be carried in a normal-size road vehicle can just as well be loaded into a container. The main objective is the enormous volume of traffic now carried by ordinary road vehicles; the more awkward loads are never likely to be anything but a sideline.

To the objection that block trains will be partly empty on most of the stages of the journey, the reply is that there are normally many unoccupied seats in a passenger train which nevertheless is remunerative to run. Such empty running, however, would probably necessitate the flat wagon brakes being of the automatic changeover empty-loaded type, but such more costly items could be justified for rolling stock used intensively.

It may be urged that running « containerised » traffic separately from other freight means more trains. On trunk lines in Britain most of the traffic already is run separately. Certain economies can be made if one train is run instead of two, but traders judge the service by factors other than « net ton-miles per train-engine hour » and the provision of a service of the necessary quality demands the separation of such traffic from other goods traffic on all lines. Other objections, such as the question of private sidings, can be similarly countered.

The cost of all the new equipment would not be prohibitive. At £100-£150 million it would not be astronomical by the stand-

ards of British Railways modernisation plan and compares with the £156 million and £75 million respectively estimated for wagon building and the fitting of power brakes to existing stock. The present-day building cost of the superseded conventional stock would be greater than the outlay on equipment as suggested above.

The proposed method offers the means of converting the outstanding rail asset of bulk trunk haulage into true competitive power, using a form of mechanical handling which extracts the maximum results from rolling stock of given capital value. In addition, it makes use of existing trackwork and buildings to such an extent that many wayside station goods yards can once again become assets. Detail improvements are always possible, but because its basic principles together form the only completely logical solution to the general merchandise problem, there is no likelihood of the system being outdated by another method.

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